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Reports
Ford,
T. M. J.

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FINAL REPORT

September 29, 1983 to March 15, 1988

Project Title: Suitability of Using Selected Ecotypes of *Hedysarum boreale* for Use in the Intermountain West.

Granting Agency: USDA-Intermountain Forest and Range Experiment Station.

Cooperators: USDA-ARS Crops Research Laboratory and Utah State University, Agricultural Experiment Station, Range Science Department.

Personnel: Douglas A. Johnson (Principal Investigator)
Timothy M. J. Ford (Graduate Student)

FINAL REPORT FOR COOPERATIVE AGREEMENT
# RNR-759)
With Utah State University
FS Contact: G. Farmer
Co-op Contact: Douglas A. Johnson

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Jim

Timothy M. J. Ford

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ABSTRACT

Establishment, Nitrogen Fixation, and Nutritive Value of Utah Sweetvetch (*Hedysarum boreale* Nutt.)

by

Timothy M. J. Ford, Master of Science

Utah State University, 1988

Major Professor: Dr. Douglas A. Johnson

Department: Range Science

Sweetvetch (*Hedysarum boreale* Nutt.) is an important legume native to the Intermountain West. A combination of field and greenhouse experiments were used to evaluate the ecotypic variation of eleven accessions of sweetvetch for seedling vigor, biomass production, acetylene reduction, and nutritive value. Significant variation was observed among the accessions for most characteristics. Accession 5 from Orem, Utah exhibited superior seedling establishment characteristics when grown under mesic conditions, while Accession 3 from Duchesne, Utah established well under xeric conditions. Accession 7 from Hobble Creek, Utah exhibited superior rhizome development, making it potentially useful in stabilizing highly erodible areas, such as highway road cuts. Although sweetvetch provided spring forage, little forage was available for fall and winter. Sweetvetch root systems have large nodules which were capable of reducing acetylene. Thus, it has high potential for use in nitrogen-limited environments, such as encountered in minelands. Because of the variabilty present within sweetvetch, great promise exists for the improvement of sweetvetch through breeding and selection.

(79 pages)

INTRODUCTION

The forb component on many rangelands has been severely depleted. On large tracts of western rangelands, undesirable introduced forbs are invading sites where the native forb component has been eliminated. The use of herbaceous native legumes in arid and semiarid areas of the United States has been limited because of restricted seed availability. Also, some forbs, such as many *Astragalus* species, have not been used for revegetation because of livestock toxicity problems (Rumbaugh, 1983).

Some forbs provide valuable forage in the early spring in the Intermountain West. Other forbs provide critical summer and fall forage to wildlife and livestock. The seeds of several forbs are valuable as food for both upland game and non-game birds (Monsen and Christensen, 1975; McArthur, 1981; Monsen and Richardson, 1984). Forbs also aid other ecosystem processes such as accumulation of litter, nutrient cycling, and soil stability (McKell and Van Epps, 1981; Monsen and Richardson, 1984). Forbs that fix nitrogen are particularly beneficial in low-nutrient rangeland environments. Nitrogen fixing forbs not only provide themselves with nitrogen, but also add nitrogen to the community through both root and shoot decomposition. Such additions of nitrogen through biological nitrogen fixation are especially important on semiarid rangelands where the use of fertilizers is usually cost prohibitive.

Forbs are becoming increasingly used in seedings in the Intermountain West (Wasser, 1982; Shaw and Monsen, 1983). "Appar" lewis flax (*Linum lewisii* L.), "Delar" small burnett (*Sanguisorba minor* Scop.), several *Penstemons*, globemallows (*Sphaeralcea* spp.), cicer milkvetch (*Astragalus cicer* L.), alfalfa (*Medicago sativa* L. and *M. falcata* L.), biennial sweet clovers (Melilotus officinalis Lam. and M. alba Medikus), sainfoin (Onobrychis viciifolia Scop.), and sweetvetch (Hedysarum boreale Nutt.) are some of the more commonly used forbs in the semiarid Intermountain West. Although the last five are legumes, only sweetvetch is native to the U.S.

Alfalfa has been the most widely used of any of the forbs in rangeland seedings. Its importance to spring, summer, fall, and winter forage production has been well demonstrated. The cost of alfalfa seed is relatively low, ranging from about $1.25 per pound ($2.75 per kilogram) for uncertified seed to approximately $4.00 per pound ($8.80 per kilogram) for some select varieties. Seed prices have increased markedly with demands through the Conservation Reserve Program. Despite its wide use in rangeland revegetation, alfalfa does have certain drawbacks. Alfalfa is not considered a native species as defined by state and federal mining regulatory agencies so that it is frequently not used for revegetating mineland. Also, in some mesic situations alfalfa tends to dominate new range seedings (Richardson, 1986). Although some seeding failures have occurred with alfalfa on extremely arid sites, alfalfa generally is considered to have excellent seedling vigor.

Use of cicer milkvetch in rangeland revegetation has been somewhat limited. However, it has shown promise in some of the more moist aspen zones of the Intermountain West (Stevens, 1980). "Monarch" and "Lutana" are two varieties of cicer milkvetch that have been released. Seed of cicer milkvetch costs about $2.50 per pound ($5.50 per kilogram). Because cicer milkvetch is not considered a native species by mining regulatory agencies, it has not been used widely in mineland reclamation.

In addition, because a number of Astragalus species are toxic to livestock, its use has been somewhat limited.

Yellow- and white-blossomed sweet clover exhibit excellent production and have a large stature. The two sweet clovers have proven useful as a green crop on nutrient depleted soils (Nichols and Johnson, 1969) and rank second to alfalfa in their use for improvement of perennial semiarid ranges (Rumbaugh, 1983). Sweetclovers have a high crude protein and have increased the yields of associated grass species (Nichols and Johnson, 1969). Sweetclovers are primarily biennials (Smith and Gorz, 1965) and in the first year grow in a rossette form with a large tap root. Second year sweet clover plants increase in height and offer cover for wildlife. They are abundant seed producers and seed costs are usually less than $1.00 per pound ($2.20 per kilogram).

Sainfoin is a productive legume with attractive pink blossoms and is winter hardy, drought resistant, and long lived. Sanfoin reportedly can extend its tap root up to 30 feet (9.1 m) into the soil profile (Ditterline and Cooper, 1975). Sainfoin produces abundant seed crops, and seed costs have remained relatively low at about $1.75 per pound ($3.85 per kilogram). Varieties of sainfoin that have been released include: "Eski," "Remont," and "Renumex". Sainfoin appears to have good seedling vigor and is capable of establishing on road cuts in the Intermountain West (Simonds, 1986).

Sweetvetch has been used to some extent in rangeland revegetation. Sweetvetch (Hedysarum boreale) was first described by Nuttall in 1818 (Redente, 1980). The name sweetvetch is synonymous with Utah sweetvetch and northern sweetvetch. It is native to western North

America and is a perennial member of the Fabaceae family. Sweetvetch has a wide range of adaptability to the foothill and lower mountain elevations of the Intermountain West. However, Plummer et al. (1968) observed that improper grazing has eliminated it from much of its original distribution. Sweetvetch initiates growth in the early spring and provides a considerable amount of early spring forage that is highly palatable to both big-game and domestic livestock.

Nitrogen fixation is a unique biological process that occurs in only a few plant genera. Biological nitrogen fixation is an obvious benefit to plants in nitrogen-limited environments. This benefit may be magnified during seedling establishment when plant rooting density is minimal. Because sweetvetch is native to the Intermountain West and has nitrogen fixing capabilities, it is an extremely appealing forb for disturbed land reclamation and range improvement in the Intermountain West (Redente and Reeves, 1981). The need for adapted native forb legumes in revegetation is great, and sweetvetch is a potentially important species in this application. However, the use of sweetvetch for revegetation has been limited to date, due primarily to its low seed availability. Availability of seed is dependent on production from wildland stands, which is often very erratic. At present the number of other adapted native legumes available for revegtation is extremely limited (Redente, 1980).

Utah sweetvetch is well adapted to semiarid areas of the Intermountain West (Redente, 1980); however, lack of water likely limits production of sweetvetch. For range plants drought is particularly critical during seedling emergence and establishment (Johnson et al., 1982). The ability of a seedling to withstand drought often determines if the species will become established in a community (Plummer, 1943). Therefore, evaluation of seedling establishment and seedling vigor under different moisture levels represents an important characteristic in the selection of improved plants for rangeland or mineland revegetation in arid and semi-arid environments.

The most recent and complete description of the Hedysarum boreale complex is by Northstrom and Welsh (1970) as revised by Northstrom (1976). Because sweetvetch has a broad ecological distribution and apparently exhibits considerable ecotypic variation for many characteristics (Plummer et al., 1968), it may have potential for revegetation of a wide diversity of sites. Ecotypic variation will form the basis for determining the potential for selecting superior ecotypes of sweetvetch.

The objective of this study was to evaluate 11 wide-ranging accessions of Utah sweetvetch for their seedling establishment characteristics, nitrogen fixation capabilities, and nutritive value.

HYPOTHESES

1. Some accessions of sweetvetch exhibit superior seedling establishment characteristics than other accessions when grown under a range of soil moisture levels.
2. Seed weight and seed production vary significantly among the 11 sweetvetch accessions.
3. Nitrogen fixation rates, as estimated by acetylene reduction, differ among the 11 accessions of Utah sweetvetch.
    a. Acetylene reduction is significantly greater in some sweetvetch

accessions than others.

  b. Acetylene reduction varies significantly when sweetvetch is grown under different soil moisture levels.

  c. Specific nodule activity is the same for all the sweetvetch accessions, but varies throughout the season.

4. Nutritive value, as estimated by forage weight, crude protein and digestibility, varies significantly among the 11 sweetvetch accessions.

METHODS

Seed was obtained from 11 sweetvetch accessions originating from different sites throughout the range of this species (Fig. 1). All sweetvetch seed used in this experiment had the loment removed. The specific locations of the collection sites, their elevations, soil types, and mean annual precipitation are presented in Table 1.

Greenhouse Study

Seeds of each of the 11 accessions were mechanically scarified and inoculated with approximately 0.1 g of Rhizobium inoculum (Nitragin Co., Milwaukee, WI) per 250 seeds. Accessions may not have been equally adapted to this Rhizobium inoculum. They were then sown in containers (length 20 cm, volume 195 cc) filled with a mixture of 1/3 sand, 1/3 peat, and 1/3 loam soil, as the potting medium. The plants were propagated in a greenhouse using well-watered conditions for approximately one month before being placed under a line-source sprinkler system (Johnson et al., 1982). The greenhouse line-source sprinkler system provides a gradient of water application. The system traverses along a central axis and applies an amount of water that decreases as distance

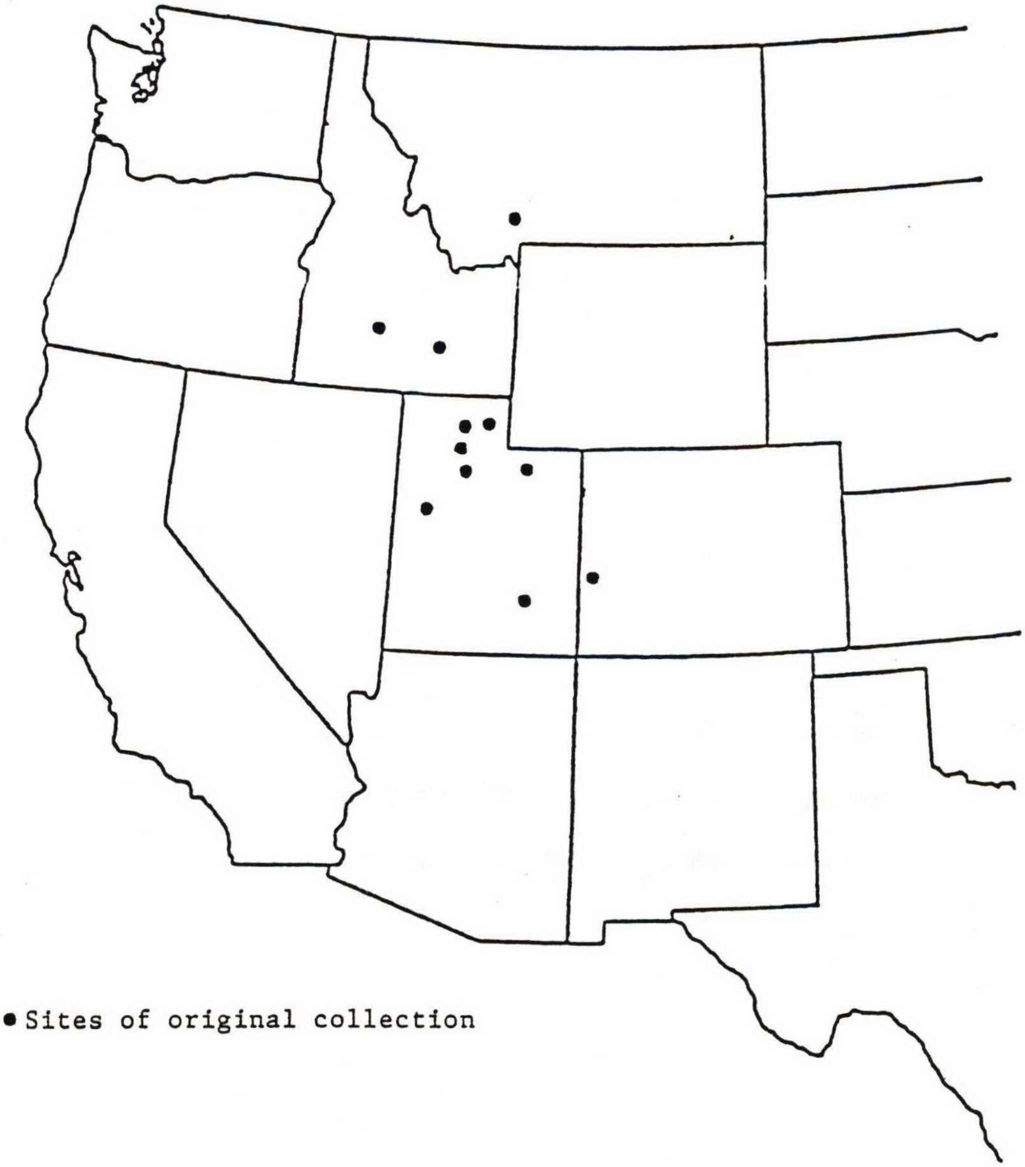
● Sites of original collection

FIGURE 1. Sites of origin of the 11 accessions of Hedysarum boreale used in this study.

Table 1. Accession numbers, origin, and site characteristics of the 11 accessions of *Hedysarum boreale*. Letter and number designations after the accession number indicate original accession designations as received.

Accession Number	Location	Elevation (m)	Soil Type	Mean Annual Precipitation (cm)
1 (B2-64)	Benmore, UT	1,739	Clay loam	33
2 (B3-82)	Arco, ID	1,525	Silty loam	28
3 (B5-67)	Duchesne, UT	1,525	Loam	33
4 (B7-77)	Ballard Mine, ID	2,074	Mine dump	48
5 (U1-79)	Orem, UT	1,586	Cobbly loam	38
6 (U2-75)	Salt Lake City, UT	1,586	Upland stony	46
7 (U9-81)	Hobble Creek, UT	1,556	Stony loam	42
8 (T1-82)	Moab, UT	1,373	Sandy	19
9 (T2-82)	Garden City, UT	1,830	Mountain Loam	57
10 (NDL-28-T15901)	Musselshell Co., MT	1,586	Loam	54
11 (EPC-1199)	Rio Blanco Co., CO	1,739	Loam	33

from the center increases. There were three replications of each accession at 10 different levels of water application. The total water applied during the 45-day growth period for each of the 10 water levels ranged from a high of 9.80 cm (123 ml) to a low of less than 0.04 cm (0.5 ml) (Fig. 2).

After the seedlings had been under the line-source sprinkler for 45 days, they were destructively harvested. The green leaves were removed and area was measured with a Licor area meter. The stems, petioles, and leaves were then oven-dried and weighed. Nitrogen fixation was estimated on a whole plant and specific nodule activity basis by acetylene reduction procedures described by Johnson and Rumbaugh (1981). Each root system was carefully extracted from the soil without washing and placed in a 60 cc plastic syringe. The syringe was filled with 54 cc of ambient air and 6 cc of washed commercial acetylene. This resulted in an atmosphere within the syringe of 10% acetylene and 90% air. The samples were incubated for one hour at ambient temperatures and shielded from direct sunlight. After incubation, gas samples of 11 cc were injected from the syringes into 10 ml stoppered Vacutainers. Ethylene content of the gas sample was determined using a gas chromatograph equipped with dual hydrogen-flame ionization detectors maintained at 150°C. Activity was expressed as moles of ethylene per hour for the whole root system and per gram of nodule dry weight.

The root systems were then washed and root lengths were determined with a Comair root scanner. Nodules were removed from the roots and counted. The roots and nodules were then oven-dried at 75° C for 48 h and weighed. Analysis of variance procedures were used to analyze the data, and LSD tests were used to evaluate statistically significant differences.

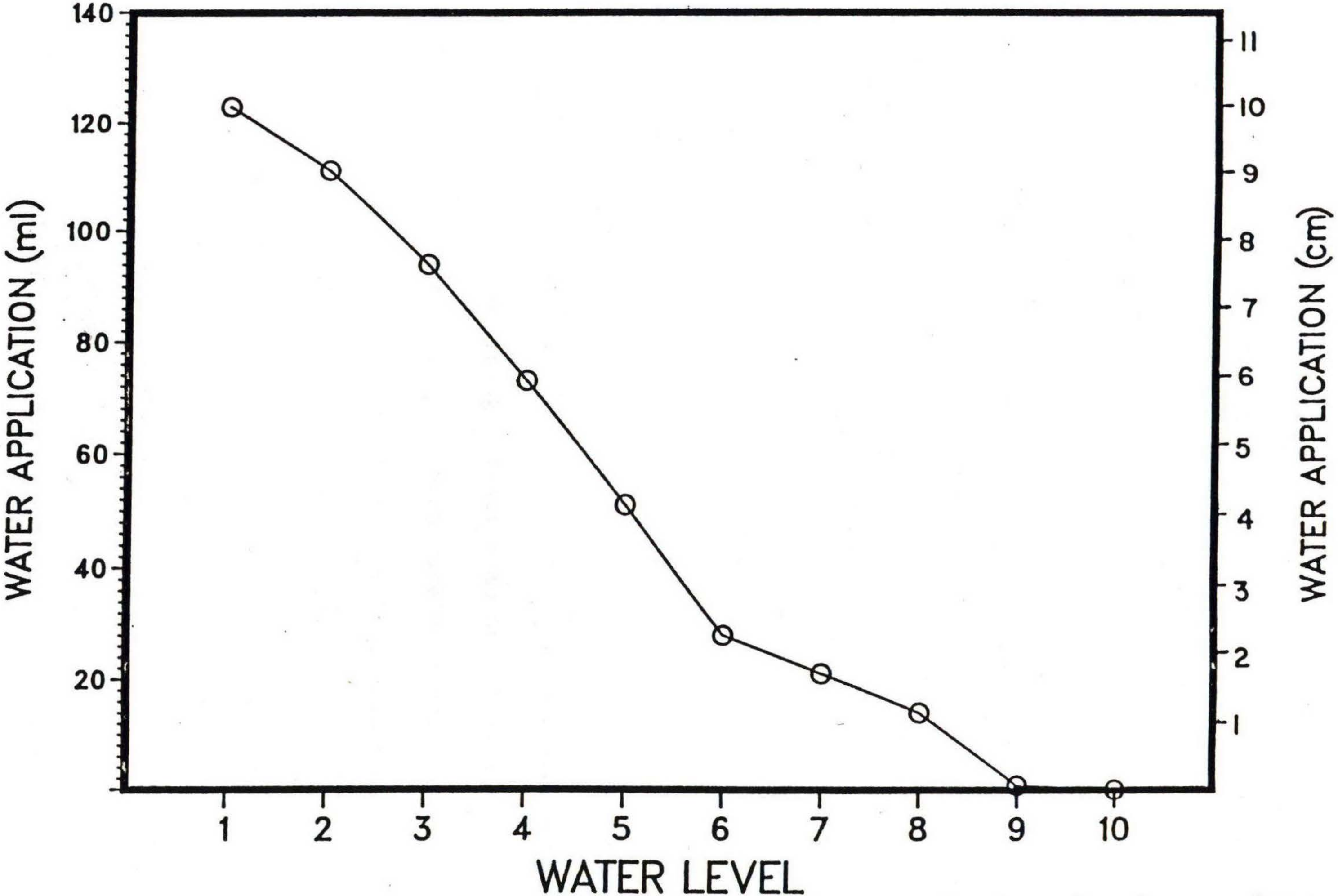

FIGURE 2. Total water applied (ml and cm) at each of the 10 water levels under the greenhouse line-source sprinkler system.

Field Study

For the field portion of the study, seeds from each accession were inoculated with commercial Rhizobium (Nitragin Co, Milwaukee, WI) and grown in the greenhouse for approximately one month prior to planting. Plants were transplanted in June, 1983 at the Evans Experimental Farm located approximately 2 km south of Logan, Utah. The soil at the site is a uniform Nibley silty clay loam with 0 to 3 percent slopes. It is a fine, mixed, mesic, Aquic Argiustoll. Precipitation at the site is primarily winter snow and spring rain and averages 17.4 inches (44.2 cm) annually (United States Department of Agriculture, 1974). During the two years that the experiment was conducted, the annual precipitation was 30.4 inches (77.2 cm) and 18.9 inches (48.0 cm), respectively (Ashcroft, 1987). Plants of NC-83 alfalfa were used as a standard for comparison. Plants were planted in a randomized block design and spaced 1 m apart.

The plants were harvested during their second growing season in 1984 on June 20-23 and October 4-6. Plants of each accession were destructively harvested using a tractor-mounted tree lifter, which cut the root systems at a depth of approximately 35 cm. Plants were then removed from the soil individually with shovels and the roots were extracted from the soil. Each plant required approximately 0.5 hour of excavation to recover the root systems. This resulted in a hole approximately 55 cm long, 45 cm wide, and 35 cm deep. Although this method did not extract the entire root system, it was a practical attempt at sampling a large portion of the root system. Nodulated root sections were placed in 120 cc syringes and nitrogen fixation was estimated for each accession using the previously described acetylene reduction technique. Roots and shoots were weighed for fresh weight, oven dried for 72 h at 65° C, and reweighed.

Four plants of each accession were randomly selected from within the sampled plants for each accession. Shoots of these plants were then ground in a Wiley mill using a 1 mm screen and placed in air-tight Mason jars until analysis for percent nitrogen by the macro-Kjeldahl technique (Harris, 1970). The nitrogen content was then multiplied by 6.25 to obtain estimates of crude protein percent. In vitro dry matter digestibility (IVDMD) was also estimated for these plants using rumen fluid from a Holstein heifer fed an alfalfa hay diet (Harris, 1970). The procedure consisted of a fermentation period of 48 h with the strained rumen fluid, followed by a 48 h incubation in hydrochloric acid-pepsin solution (Harris, 1970). Analysis of variance procedures were used to analyze the data, and accession differences were tested for significance using LSD tests.

RESULTS AND DISCUSSION

Seed weight has been shown to be positively correlated with seedling vigor in several plant species (Trupp and Carlson, 1971; Asay and Johnson, 1980). Most studies have shown that large seeds within a species generally exhibit the best vigor during germination and initial stages of seedling growth (Kneebone and Cremer, 1955; Wright, 1971). Seedling vigor in alfalfa has been related to seed weight in some circumstances (Erikson, 1946; Beveridge and Wilsie, 1959) but not in others (Smith, 1961; Nel and Berger, 1968). Fransen and Cooper (1976) concluded that seed weight is most related to seedling vigor in small-seeded legumes. Lawrence (1957) reported that for intermediate wheatgrass (Agropyron intermedium), seed weight was of little value as a selection criterion. Similarly, percent emergence was not affected by seed weight in cereal grains (Kaufmann, 1958; Kaufmann and McFadden, 1963; Pintbus and Osher, 1966).

Seed weight has been used in screening for seedling vigor in vegetable crops (Bradnock and Matthews, 1970; Ching and Danielson, 1972; Hillel and Smith, 1974), cereal grains (McDaniel, 1969; Austenson and Walton, 1970; Glenn et al., 1974), and forage grasses (Tossell, 1960; Trupp and Carlson, 1971; Asay and Johnson, 1980). However, screening for seed weight in arid and semiarid shrubs and forbs has not been widespread. If seed weight is used for screening, it is important that the seeds are produced under uniform environmental conditions. The Syn. 1 generation seed weights probably more accurately reflect genotypic differences because all accessions were grown in the same environment. Seed weights for the 11 sweetvetch accessions (Table 2) indicated that significant differences were present among accessions both in the seeds of the original collections and the Syn. 1 generation, supporting Hypothesis 2. Seed weights for 25 seeds of the 11 accessions were higher for the Syn. 1 generation (0.149 to 0.278 g) than the original collections (0.137 to 0.243 g). This is probably due to the more favorable growth conditions at the Evans Farm compared to the sites of origin. Although changes in accession rank occurred between generations, the five accessions with the heaviest seed in the original collections also exhibited the greatest seed weight in the Syn. 1 generation.

Table 2. Weight (g) of 25 seeds for the original collections and the Syn. 1 generation of the 11 sweetvetch accessions. Each value represents the mean of four replications.

Original Collections		Syn. 1 Generation	
Accession	Seed weight (g)	Accession	Seed weight (g)
4	0.243 a	5	0.278 a
8	0.229 ab	7	0.272 ab
6	0.228 ab	4	0.271 ab
5	0.223 b	6	0.260 abc
7	0.203 c	8	0.255 bc
2	0.199 d	9	0.239 cd
9	0.188 de	1	0.226 de
11	0.176 ef	3	0.213 ef
1	0.166 fg	2	0.211 ef
10	0.149 gh	11	0.199 f
3	0.137 h	10	0.149 g
LSD .05	0.018		0.023

Greenhouse Experiment

Imbibition, germination, emergence, and initial seedling growth are critical for successful plant establishment. In the Intermountain West there is usually adequate soil moisture for imbibition and germination. However, after germination, seedling growth can be limited by drought. Establishment can be severely affected by soil drying during early summer. The greenhouse experiment was designed to simulate this early summer drying period.

Sweetvetch allocated a greater proportion of its weight to roots than shoots as water application declined (Fig. 3). Total biomass remained relatively constant throughout the first 8 water levels. Root/shoot ratios at water levels 1 and 2 were about 1.1 and increased to a high of 1.7 at water level 7 (Fig. 4). Root/shoot ratios dropped off markedly at water level 9.

The 10 levels under the line-source sprinkler system were combined into three groups based on total water applied. The three groups approximately represented excess water, adequate water, and limited water. Shoot mass gradually declined over the three combined water levels (Table 3), whereas root mass was greatest at the middle level of water application (Table 4). Significant differences were observed among the accessions for both shoot and root mass, supporting Hypothesis 1. Accession 5 had the greatest shoot and root mass at the highest water level. Accession 3 had the greatest root mass and the second greatest shoot mass at the lowest water level.

Total root length provides an estimate of the amount of soil volume the roots are exploring, whereas root mass is an indication of root

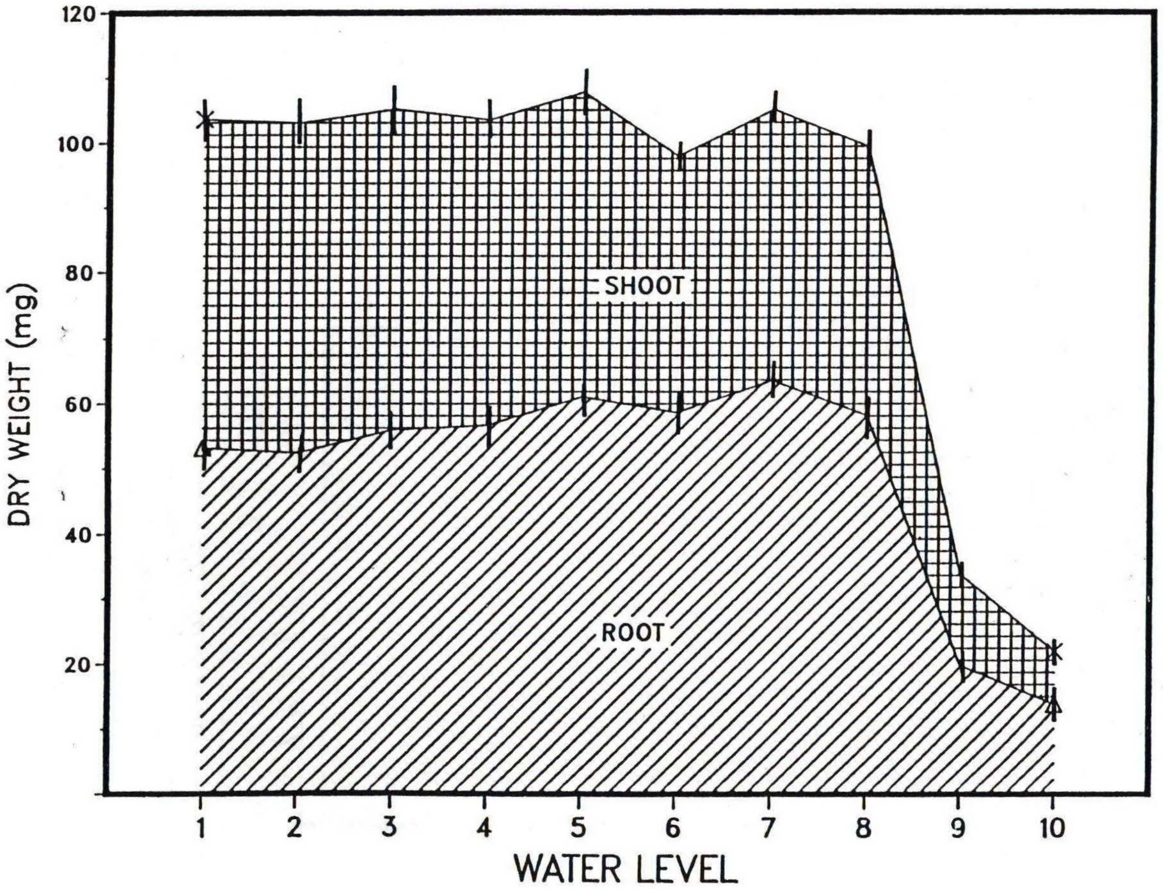

FIGURE 3. Average root and shoot dry weights (mg) for the 11 sweetvetch accessions at each of the 10 water levels under the greenhouse line-source sprinkler system. Lines represent ± 1 S.E. Standard errors ranged from 3.6 to 4.5 and 3.0 to 4.8 for root and shoot dry weights; respectively. Each value represents the mean of 33 observations.

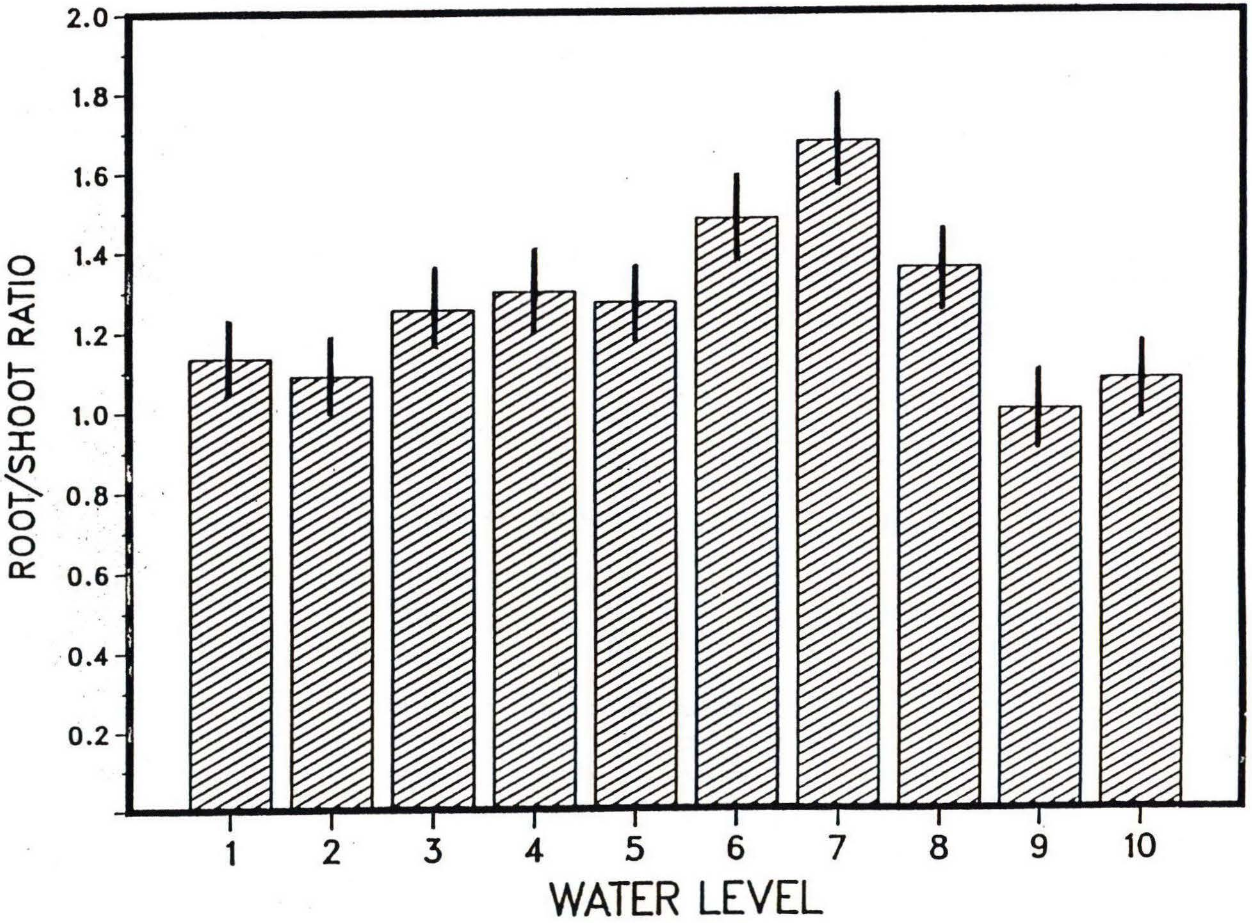

FIGURE 4. Average root/shoot ratios for the 11 sweetvetch accessions at each of the 10 water levels under the greenhouse line-source sprinkler system. Lines on the top of each bar represent ± 1 SE. Standard errors ranged from .10 to .13. Each value represents the mean of 33 observations.

Table 3. Shoot mass (g) of the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water levels.

Water levels 1-3		Water levels 4-7		Water levels 8-10	
Accession	Shoot Mass (g)	Accession	Shoot Mass (g)	Accession	Shoot Mass (g)
5	0.078 a	4	0.062 a	6	0.031 a
4	0.075 a	8	0.052 ab	3	0.026 ab
7	0.074 a	7	0.051 abc	5	0.026 ab
11	0.052 b	5	0.098 abcd	1	0.026 ab
6	0.048 bc	9	0.048 abcd	7	0.023 ab
2	0.042 bc	11	0.046 bcd	4	0.022 ab
10	0.041 bc	3	0.038 bcd	8	0.018 ab
8	0.040 bc	2	0.035 cd	9	0.018 ab
3	0.037 bc	10	0.035 d	2	0.017 ab
9	0.034 bc	6	0.033 d	10	0.013 ab
1	0.031 c	1	0.031 d	11	0.009 b
Mean	0.050		0.042		0.021
*LSD 0.05	0.018		0.015		0.018

Table 4. Root mass (g) of the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level.

Water levels 1-3		Water levels 4-7		Water levels 8-10	
Accession	Root Mass (g)	Accession	Root Mass (g)	Accession	Root Mass (g)
5	0.076 a	9	0.086 a	3	0.049a
7	0.076 a	5	0.070 ab	1	0.044ab
10	0.061 ab	4	0.066 b	5	0.040ab
4	0.060 ab	7	0.065 b	8	0.035ab
11	0.056 ab	8	0.065 b	6	0.030abc
3	0.056 ab	3	0.060 bc	9	0.028abc
9	0.049 bc	11	0.060 bc	4	0.025bc
1	0.045 bc	10	0.056 bc	2	0.025bc
2	0.045 bc	2	0.053 bcd	10	0.025bc
6	0.033 c	1	0.043 cd	7	0.025bc
8	0.033 c	6	0.037 d	11	0.011c
Mean	0.054		0.060		0.031
*LSD 0.05	0.021		0.018		0.021

carbon and nutrient investment. Similarily, green leaf area provides an estimate of the seedling photosynthetic area available, whereas shoot mass is an indication of shoot carbon and nutrient allocation. As water application declined from level 1 to 10, the green leaf area declined, reducing transpirational area (Fig. 5). Total root length increased from level 1 to level 7, increasing the soil volume explored for water and nutrients (Fig. 5). Total root length decreased markedly from water level 7 to water level 10. Little mortality occurred until water level 8. At water level 8, approximately 10% death occurred. At water level 9, 90% of the seedlings died. By water level 10, virtually all plants were dead. Total root length and green leaf area differed significantly among accessions (Table 5 and 6), supporting Hypothesis 1. Accession 5 tended to have the greatest root length and leaf area at the high and middle water levels, while Accession 3 exhibited the greatest root length and green leaf area at the lowest water level.

To ensure successful seedling establishment, a seed should germinate quickly and initiate rapid radical cell elongation and subsequent root development (Blaisdell, 1949; Ross and Harper, 1972; Grubb, 1977; and Platt and Weis, 1985). The seedling root needs to quickly explore a large soil volume and penetrate the soil profile as deeply as possible to aid in water uptake as the soil profile dries during the summer. Because such a strategy would probably result in a competitive advantage, total root length development in sweetvetch seedlings is probably an important screening tool for establishment in semiarid environments. Total root length gives an indication of soil volume explored, whereas root mass estimates resource allocation to roots.

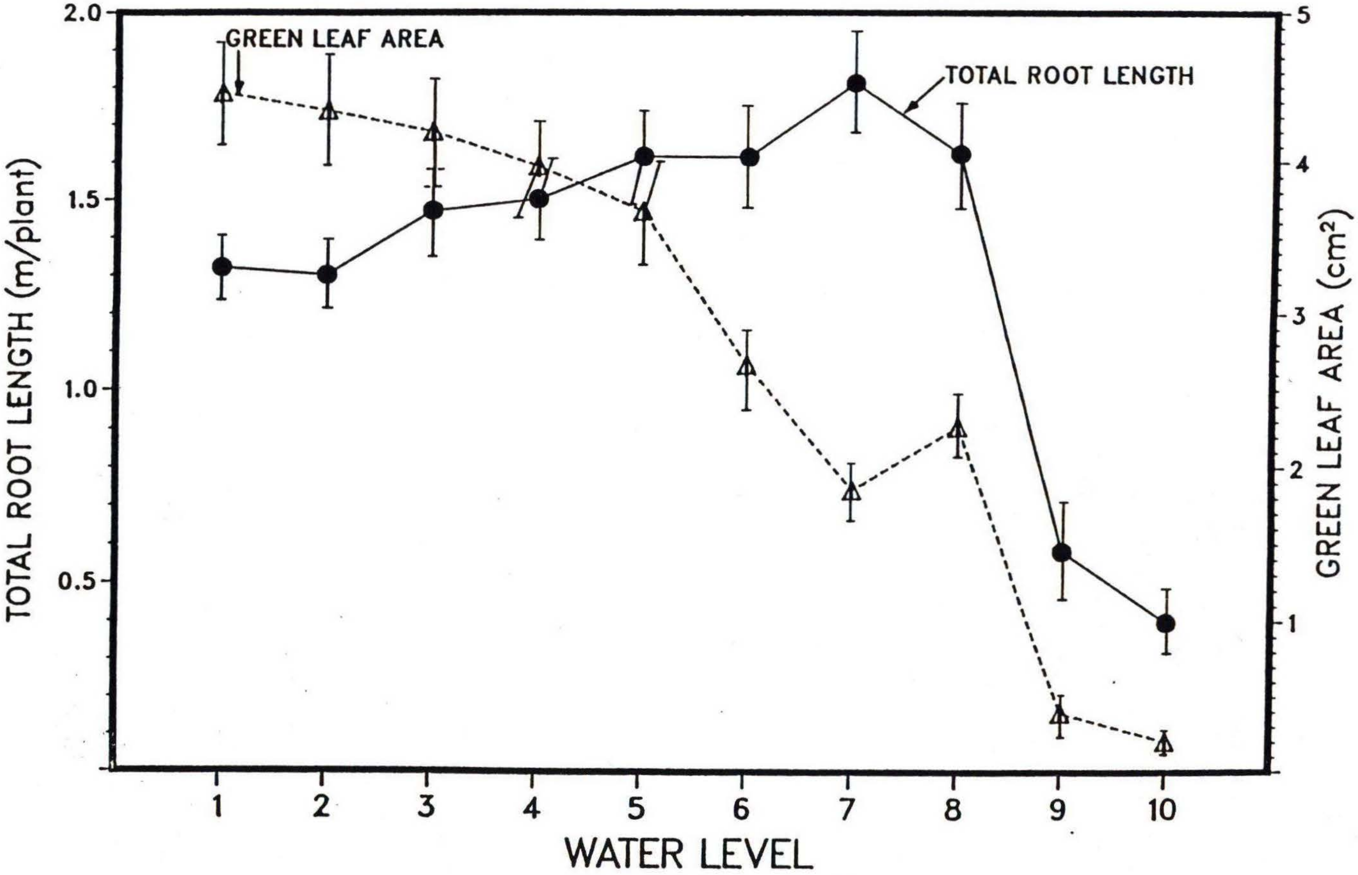

FIGURE 5. Total root length (m/plant) and green leaf area (cm^2) for the 11 sweetvetch accessions at each of the 10 levels of water application under the greenhouse line-source sprinkler system. Lines represent ± 1 S.E. Standard errors ranged from 0.10 to 0.14 and 0.08 to 0.42 for total root length and green leaf area; respectively. Each value represents the mean of 33 observations.

Table 5. Root lengths (m) of the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level.

Water levels 1-3		Water levels 4-7		Water levels 8-10	
Accession	Root Length (m)	Accession	Root Length (m)	Accession	Root Length (m)
5	1.77 a	5	2.09 a	3	1.38 a
7	1.73 a	9	1.90 b	5	1.14 b
4	1.70 a	11	1.88 bc	1	1.08 b
11	1.58 ab	8	1.80 bcd	2	0.98 b
2	1.43 bc	2	1.78 cd	8	0.96 b
1	1.37 c	7	1.75 cd	6	0.95 b
10	1.36 c	4	1.71 d	9	0.74 c
9	1.26 c	1	1.40 e	4	0.73 c
6	1.01 d	10	1.35 ef	7	0.72 cd
3	0.98 de	3	1.21 fg	10	0.53 d
8	0.80 e	6	1.10 g	11	0.31 e
Mean	1.36		1.63		0.87
*LSD 0.05	0.19		0.16		0.19

Table 6. Green leaf area (cm^2) of the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level.

Water levels 1-3		Water levels 4-7		Water levels 8-10	
Accession	Leaf area (cm^2)	Accession	Leaf area (cm^2)	Accession	Leaf area (cm^2)
5	7.0 a	4	3.9 a	3	1.8 a
7	6.7 ab	7	3.8 a	1	1.4 a
4	5.4 bc	5	3.5 a	2	1.3 a
10	4.3 cd	9	3.3 ab	6	1.3 a
11	4.3 cd	2	3.1 ab	9	1.1 a
2	4.2 cde	11	3.0 ab	7	0.8 a
6	4.1 cde	8	2.9 ab	5	0.7 a
3	3.8 de	3	2.9 ab	8	0.7 a
9	3.1 def	6	2.8 ab	10	0.7 a
8	2.7 ef	10	2.1 b	4	0.5 a
1	2.1 f	1	2.1 b	11	0.4 a
Mean	4.3		3.0		1.0
*LSD 0.05	1.5		1.3		1.5

Green leaf area also could potentially be an important screening tool and aid establishment success of sweetvetch. During high soil moisture periods, it would be important that photosynthesis is as great as possible to take advantage of favorable growing conditions. During dry periods, if a plant can maintain green leaf area and photosynthesis, it may be able to effectively lengthen its growth period. Thus, green leaf area at the lower levels of water application represents an important measurement.

Nitrogen fixation is a unique biological process that may benefit plants growing in nitrogen-limited environments. This benefit may be magnified during the seedling establishment stage when rooting density is minimal. However, because of the energy costs associated with biological nitrogen fixation, it may be one of the first plant functions curtailed when sweetvetch is exposed to drought. Consequently, it is important to determine if sweetvetch accessions vary in ability to fix nitrogen under water stress conditions.

Number of nodules remained relatively constant for the first eight water levels, then dropped rapidly as plant death occurred (Fig. 6), indicating that number of nodules was quite tolerant to decreasing water level. Nodule mass showed a gradual decline as water decreased from water level 1 to water level 8, after which nodule mass dropped off markedly (Fig. 6).

Combining data into three water level groups, Accessions 2, 4, and 5 exhibited the greatest number of nodules and nodule mass at the high level of water application (Tables 7 and 8); Accession 3 had the greatest number of nodules and nodule mass at the lowest level of water application. Both traits decreased as the level of water application

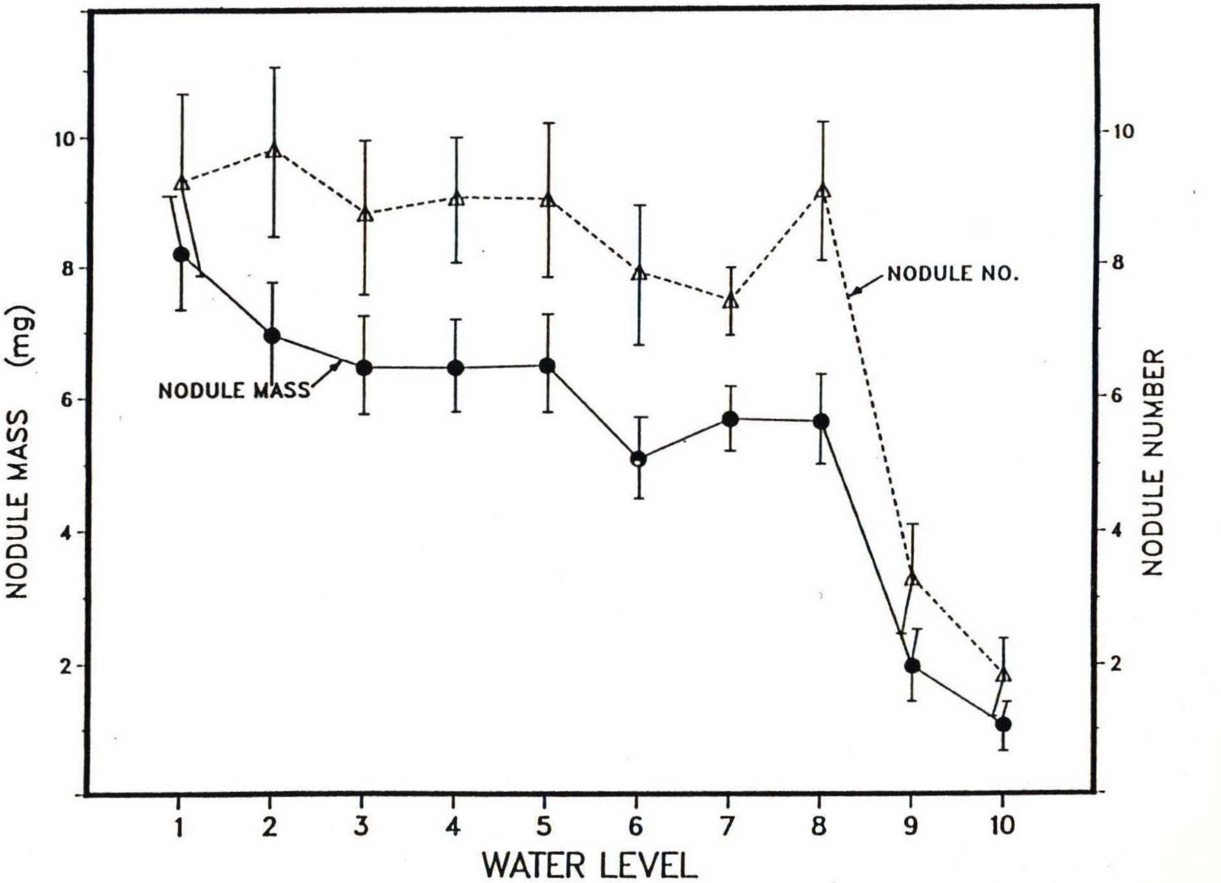

FIGURE 6. Average nodule mass (mg) and number of nodules for the 11 sweetvetch accessions at the 10 levels of water application under the greenhouse line-source sprinkler system. Lines represent ± 1 S.E. Standard errors ranged from 0.36 to 0.88 and 0.6 t0 1.4 nodule mass and nodule number; respectively. Each value represents the mean of 33 observations.

Table 7. Number of nodules for the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level.

Water Levels 1-3		Water Levels 4-7		Water Levels 8-10	
Accession	No.*	Accession	No.*	Accession	No.*
4	15.2 a	2	13.6 a	3	9.4 a
5	14.1 ab	4	12.8 ab	2	7.9 ab
2	12.7 abc	3	10.3 abc	5	7.3 abc
3	12.1 abc	5	8.8 bcd	4	5.6 abcd
9	11.6 abc	8	8.1 cde	6	5.1 abcd
7	9.3 bcd	7	7.9 cde	9	4.3 abcd
11	8.7 cd	11	7.6 cde	1	3.8 bcd
6	5.6 de	9	6.4 cde	7	2.4 cd
10	5.4 de	6	6.1 cde	11	2.3 cd
8	4.3 de	1	5.8 de	8	2.1 cd
1	3.4 e	10	4.3 e	10	2.0 d
Mean	9.3		8.3		4.7
LSD 0.05	5.2		4.3		5.2

Table 8. Nodule mass (mg) for the 11 sweetvetch accessions at the three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and twelve observations for the middle water level.

Water Levels 1-3		Water Levels 4-7		Water Levels 8-10	
Accession	Mass (mg)	Accession	Mass (mg)	Accession	Mass (mg)
4	11.5 a	4	9.4 a	3	5.3 a
2	10.7 ab	5	8.7 ab	1	4.2 ab
5	9.1 abc	2	7.4 abc	6	4.0 ab
10	8.5 abc	7	6.6 bcd	5	3.8 ab
11	8.0 bc	3	6.2 bcde	2	3.3 ab
3	7.4 bc	9	5.8 cdef	4	2.8 ab
9	6.9 cd	10	4.8 cdef	10	2.1 b
7	6.6 cde	11	4.7 def	8	2.0 b
6	3.9 def	8	4.4 def	7	1.4 b
8	3.7 ef	6	3.5 ef	9	1.4 b
1	2.5 f	1	3.2 ef	11	1.2 b
Mean	7.2		5.9		2.9
LSD 0.05	3.2		2.7		3.2

decreased. Nodule mass decreased as water decreased, indicating that sweetvetch may curtail resource allocation to nodules as water becomes more limiting.

Acetylene reduction activity (Fig. 7) and specific nodule activity (Fig. 8) remained relatively constant over the first five water levels, then dropped off markedly, supporting Hypothesis 3b. Similar to nodule mass, acetylene reduction activity both on a whole plant and specific nodule basis appeared more sensitive to drought than the other plant characteristics examined. When water levels were combined, Accessions 4 and 5 had the greatest acetylene reduction activity per plant at the highest water level; no significant differences were apparent at the lowest water level (Table 9). No significant differences in specific nodule activity were detected when data were combined over water levels (Table 10).

It is interesting to note that Accession 5 exhibited the best seedling growth at the higher water levels under the greenhouse line-source sprinkler system (Tables 3, 4, 5, 6, 7, 9) and also had one of the highest seed weights (Table 2). Conversely, Accession 3, which showed the best seedling growth at drier water levels under the line-source sprinkler system, had one of the lowest seed weights. This suggests that higher seed weight may be an important initial screening test in environments where precipitation is adequate, but that high seed weight may not be a desirable characteristic when screening for drought tolerance. Similarly, Wright and Brauen (1971) found that for Lehman lovegrass (*Eragrostis lehmanniana* Nees), lines with the heaviest seeds were generally the most drought susceptible.

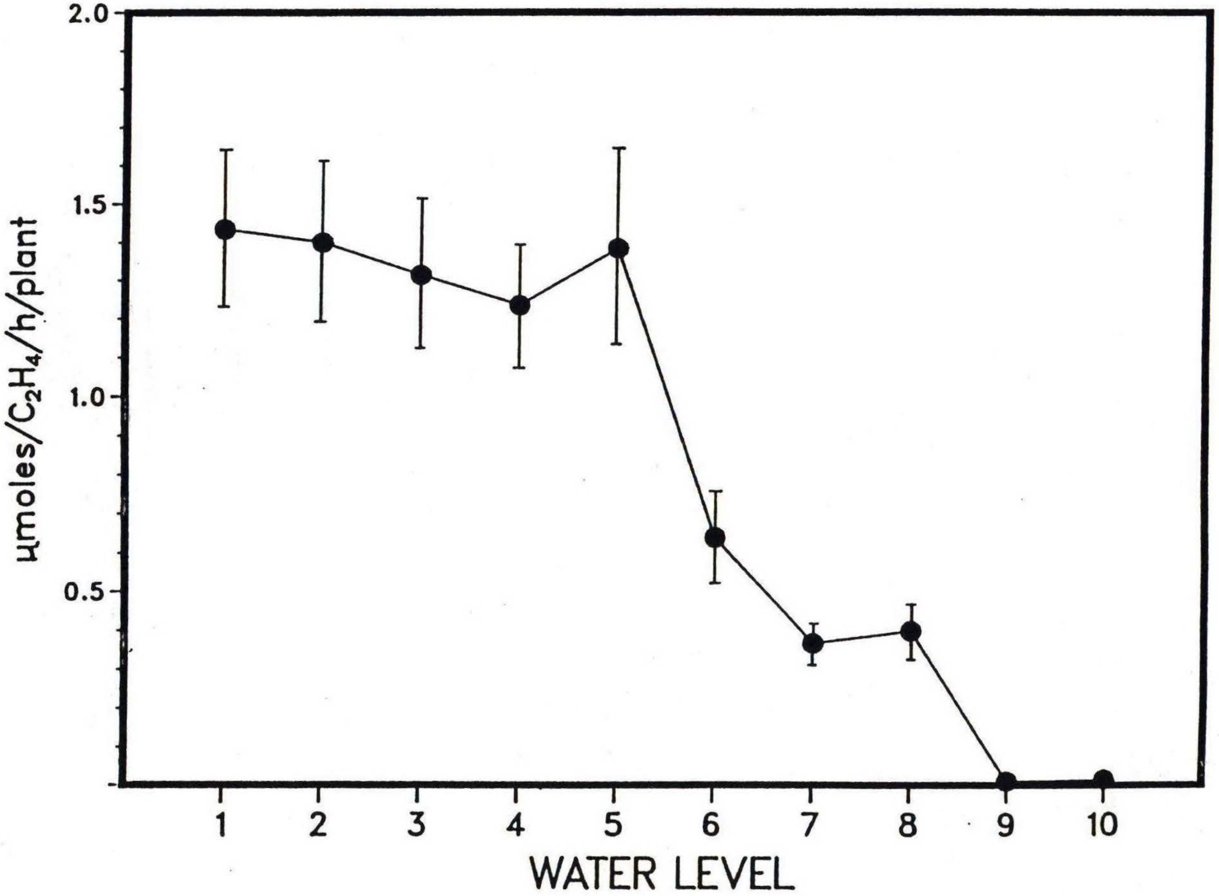

FIGURE 7. Mean acetylene reduction activity (µmoles C_2H_4/h/plant) of the 11 sweetvetch accessions at the 10 levels of water application under the greenhouse line-source sprinkler system. Lines represent ± 1 S.E. Standard errors ranged from 0.004 to 0.247. Each value represents the mean of 33 observations.

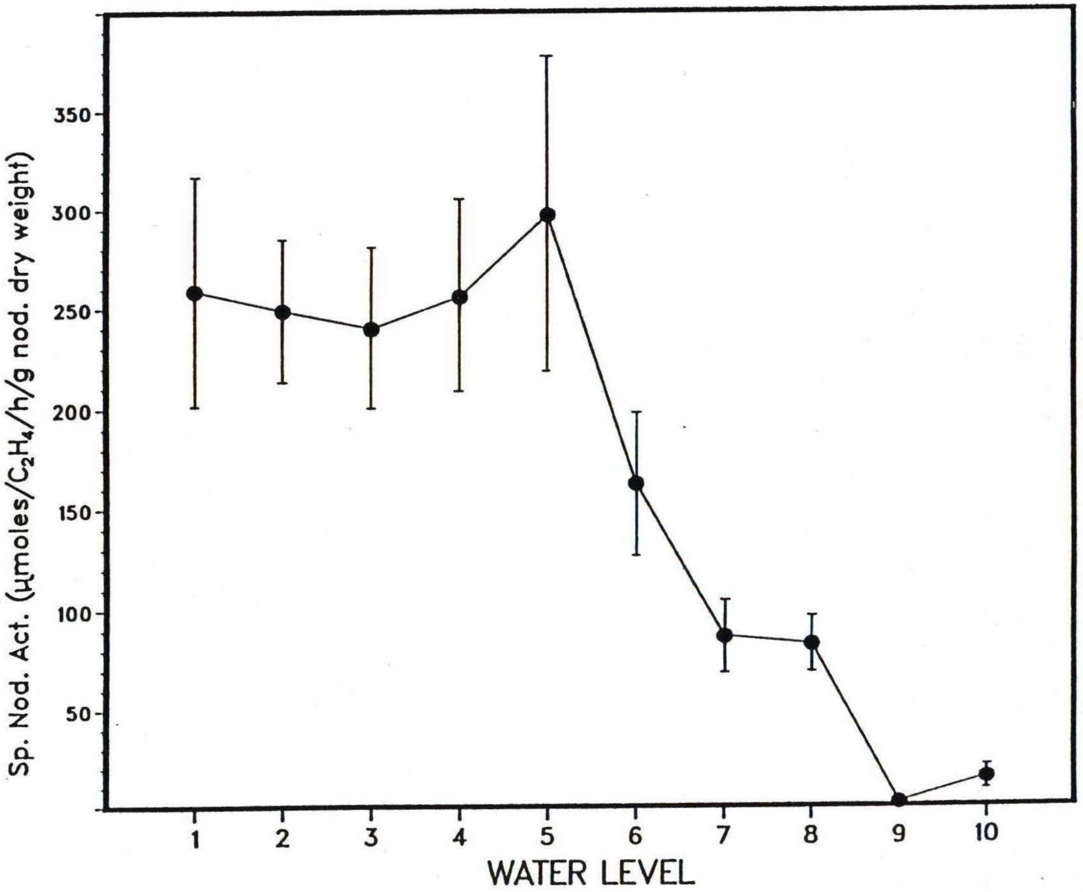

FIGURE 8. Mean specific nodule activity (μmoles C_2H_4/h/g nodule dry weight) for the 11 sweetvetch accessions at the 10 levels of water application under the greenhouse line-source sprinkler system. Lines represent ±1 S.E. Standard errors ranged from 1 to 80. Each value represents the mean of 33 observations.

Table 9. Acetylene reduction activity (ARA) expressed as µmoles C_2H_4/h/plant for the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level.

Water Levels 1-3		Water Levels 4-7		Water Levels 8-10	
Accession	ARA	Accession	ARA	Accession	ARA
5	2.77 a	2	1.28 a	2	0.32
4	2.22 ab	7	1.22 ab	3	0.27
7	1.93 bc	5	1.16 ab	6	0.21
10	1.61 bcd	9	1.01 abc	10	0.19
3	1.38 cde	3	0.90 abc	1	0.14
2	1.35 cde	6	0.81 abc	5	0.12
9	1.20 def	1	0.73 bc	9	0.10
11	0.94 ef	11	0.73 bc	8	0.08
6	0.83 efg	4	0.66 bc	7	0.03
8	0.64 fg	8	0.57 c	4	0.03
1	0.19 g	10	0.57 c	11	0.03
Mean	1.37		0.88		0.14
LSD 0.05	0.65		0.56		N.S.

Table 10. Specific nodule activity (SNA) expressed as μmoles C_2H_4/h/g nodule dry weight for the 11 sweetvetch accessions at three combined water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the highest and lowest water levels and 12 observations for the middle water level. Analysis of variance indicated no statistically significant differences.

Water Levels 1-3		Water Levels 4-7		Water Levels 8-10	
Accession	SNA	Accession	SNA	Accession	SNA
5	396.03	7	300.43	2	77.65
7	383.64	10	278.95	10	53.62
8	318.34	9	262.16	3	48.57
6	292.00	2	225.19	9	37.64
9	251.26	1	203.55	6	32.66
3	223.84	6	178.17	8	30.21
11	217.87	11	171.19	7	29.05
10	200.07	3	158.12	11	17.38
4	195.46	5	140.16	5	14.59
2	155.09	8	120.36	1	13.96
1	46.04	4	99.23	4	4.54
Mean	243.60		194.32		32.72

Field Portion of Results

The field portion of the study consisted of destructively harvesting plants during their second growing season to estimate the amount of forage available in early summer and fall. At the first harvest sweetvetch was in full bloom, whereas alfalfa was at one tenth bloom. Because of this maturity difference, direct comparisons between alfalfa and sweetvetch may be somewhat limited.

Sweetvetch provided considerable forage at the first harvest (Table 11); however, alfalfa produced significantly more forage than any of the sweetvetch accessions. Accession 5 had the greatest forage weight of the 11 sweetvetch accessions with a total of 168 g/plant. Significant differences were observed among the accessions, supporting Hypothesis 4. Percent crude protein did not vary among the sweetvetch accessions, failing to support Hypothesis 4.

Nitrogen yield or total crude protein for the first harvest was by far the greatest for alfalfa (49 g/plant). Accession 5 had the highest nitrogen yield of the sweetvetch accessions with 26 g per plant, but this was not significantly different from Accessions 4, 7, and 3. Accession 9 had the lowest nitrogen yield. In vitro dry matter digestibility (IVDMD) was highest for alfalfa at the first harvest; however, sweetvetch Accession 1 was not significantly different from alfalfa. Accession 11 had the lowest IVDMD.

The second harvest showed that sweetvetch has minimal value as a fall forage (Table 12). At this harvest plants were mainly senesced and had very few leaves. In addition, sweetvetch growth at this harvest was prostrate making herbivore accessibility to herbaceous material difficult, particularly if snow were present. Few significant

Table 11. Forage dry weight (g/plant), crude protein content (%), total crude protein (g/plant), and in-vitro dry matter digestibility (IVDMD, %) of alfalfa and the 11 sweetvetch accessions for the first field harvest (June 20-23, 1984). Each value represents the mean of 4 observations.

Acc.	Forage Wt. (g/plant)	Acc.	Crude Protein (%)	Acc.	Total Crude Protein (g)	Acc.	IVDMD (%)
Alfalfa	279 a	Alfalfa	17.6	Alfalfa	49.1 a	Alfalfa	61.8 a
5	168 b	4	17.3	5	26.2 b	1	54.8 ab
4	126 bc	7	17.0	4	21.8 bc	9	52.9 b
7	122 bc	3	16.6	7	20.7 bc	7	52.9 b
6	120 bc	9	16.2	3	19.4 bc	6	52.4 b
3	117 cd	8	16.2	6	18.2 c	4	51.7 b
2	97 cde	11	16.0	2	15.4 cd	3	50.0 bc
10	69 de	1	16.0	8	10.4 d	8	49.9 bc
11	64 de	2	15.9	11	10.2 d	10	49.1 bc
8	64 de	5	15.6	10	8.9 d	2	48.8 bc
1	54 e	6	15.2	1	8.6 d	5	48.4 bc
9	41 e	10	12.9	9	6.6 e	11	43.9 c
LSD (0.05)	48		N.S.		7.2		7.0

Table 12. Forage dry weight (g/plant), crude protein content (%), total crude protein (g/plant), and in-vitro dry matter digestibility (IVDMD, %) of alfalfa and the 11 sweetvetch accessions for the second field harvest (Oct. 4-6, 1984). Each value represents the mean of 4 observations.

Acc.	Forage wt. (g/plant)	Acc.	Crude Protein (%)	Acc.	Total Crude Protein (g)	Acc.	IVDMD (%)
Alfalfa	1167 a	Alfalfa	10.7 a	Alfalfa	124.8 a	10	49.3
10	135 b	11	10.3 a	10	10.0 b	8	47.6
7	115 b	2	10.2 a	6	8.4 b	11	41.3
6	96 b	5	9.4 ab	2	8.3 b	Alfalfa	41.2
4	87 b	6	8.8 abc	7	7.2 b	2	40.2
8	85 b	8	8.1 bc	8	6.9 b	3	38.6
3	83 b	1	8.0 bc	4	6.8 b	9	38.5
2	82 b	9	8.0 bc	3	6.5 b	7	37.6
5	68 b	4	7.8 bc	5	6.3 b	5	36.1
1	62 b	3	7.8 bc	11	5.9 b	1	35.7
11	57 b	10	7.4 c	1	5.0 b	6	30.2
9	45 b	7	5.4 d	9	3.6 b	4	28.8
LSD(0.05)	173		1.91		18.5		N.S.

differences were present among sweetvetch accessions for fall forage characteristics. Forage weight and total crude protein for the sweetvetch accessions were less for the second harvest compared to the first harvest. On the other hand, alfalfa increased in both forage weight and total crude protein, indicating alfalfa's value as a fall forage. Percent crude protein for some of the sweetvetch accessions was relatively high at the second harvest so that sweetvetch could possibly be used to supplement cured grass. Accession 10, which was one of the poorest accessions at the first harvest, ranked at or near the top for forage weight, total crude protein, and IVDMD at the second harvest. This difference in response may be due to phenological differences because Accession 10, which originated from the northern-most location, appeared to start growth later in the spring and actively grew later into the summer.

Accessions 5, 3, and 4 had significantly higher values of total acetylene reduced per plant than the other accessions for the first harvest (Table 13), supporting Hypothesis 3a. Accession 3 also had a significantly higher specific nodule activity than the other accessions except for Accession 5, failing to support Hypothesis 3b. Nodule mass also varied significantly among the 11 accessions. Acetylene reduction activity was extremely low during the second harvest, with no significant differences among accessions (Table 14), indicating that nodule activity in sweetvetch coincides with the period of most active growth, supporting Hypothesis 3c. Nodule mass was generally lower for the second harvest, except that Accession 10 went from the lowest nodule mass at the first harvest to the highest nodule mass at the

Table 13. Total acetylene reduced (TAR, µmoles C_2H_4/h/plant), specific nodule activity (SNA, µmoles C_2H_4/g nodule dry weight), and nodule mass (g/plant) for the first field harvest (June 20-23, 1984). Each value represents the mean of 12 observations.

Acc.	TAR (µmoles C_2H_4/h/plant)	Acc.	SNA (µmoles C_2H_4/g)	Acc.	Nodule Mass (g/plant)
5	97 a	3	157 a	5	1.01 a
3	90 a	5	112 ab	4	0.98 a
4	81 ab	1	87 bc	6	0.61 ab
8	39 bc	11	77 bc	3	0.61 ab
6	38 bc	6	71 bc	7	0.59 ab
1	38 bc	9	68 bc	8	0.33 bc
11	31 c	4	67 bc	1	0.33 bc
7	30 c	8	60 bc	11	0.33 bc
2	22 c	7	56 bc	2	0.30 bc
9	16 c	2	50 c	9	0.10 c
10	10 c	10	28 c	10	0.05 c
LSD (0.05)	44		48		0.42

Table 14. Total acetylene reduced (TAR, μmoles C_2H_4/h/plant), specific nodule activity (SNA, μmoles C_2H_4/h/g nodule dry weight), and nodule mass (g/plant) of the 11 sweetvetch accessions for the second field harvest (Oct. 4-6, 1984). Each value represents the mean of 11 observations.

	TAR		SNA		Nodule Mass
Acc.	(μ moles C_2H_4/h/plant)	Acc.	(μ moles C_2H_4/h/g)	Acc.	(g/plant)
10	1.48	2	3.36	10	1.41 a
8	0.78	8	1.50	3	0.51 b
5	0.24	11	1.43	6	0.38 bc
6	0.22	10	0.99	1	0.34 bc
4	0.22	4	0.77	8	0.33 bc
3	0.16	5	0.48	11	0.31 bc
11	0.12	6	0.48	7	0.28 bc
9	0.09	9	0.25	5	0.26 bc
2	0.01	3	0.15	9	0.23 bc
1	0.00	1	0.00	4	0.14 c
7	0.00	7	0.00	2	0.11 c
LSD (0.05)	N.S.		N.S.		0.30

second harvest. No nodulation occurred for alfalfa in the field experiment. Two other significant findings were that some sweetvetch accessions displayed fall regrowth and rhizome development (Table 15). Seven out of 11 accessions exhibited fall regrowth, whereas only Accessions 7, 9, and 10 showed any rhizome development. Fall regrowth is important for fall forage value and rhizome development is important for erosion control. Both traits could possibly be selected and bred for within sweetvetch.

Sweetvetch is apparently a cross-pollinated species and requires insect pollination. The flowers are extremely entimophilous, and several species of native pollinators were observed pollinating sweetvetch flowers during anthesis. The need for additional pollinators apparently does not exist because seed set appeared quite good. Ample sweetvetch flower visitation was also noted on a seed production farm near Woodruff, Utah by the Bee Pollination Laboratory at Utah State University (Tepedino and Stackhouse, 1987). However, the need for additional pollinators may exist on other production sites.

Sweetvetch appears amenable to mechanical seed harvesting; however, timing is very critical. Sweetvetch must be swathed and windrowed with a "draper type" swather to avoid shattering before the loments dehisce. Swathing too early results in shrivelled seed and low viability. Swathing too late results in a loss of seed due to seed shattering. Sweetvetch should be swathed to a 12 cm height to avoid injury to the plants. After the plant material has been windrowed, it should be allowed to dry for 3 to 5 days. Then, with the proper sieve setting, screens, and air the windrow can be picked up and threshed with a commercial combine with minimal seed loss. This process has proven effective at a sweetvetch production farm near Woodruff, Utah.

Table 15. Percentage of plants exhibiting fall regrowth, oven-dried regrowth forage weights (g), and percentage of plants exhibiting rhizome development of the 11 sweetvetch accessions growing in the field as determined on Oct. 1, 1984. Each value represents the mean of 11 replications. Analysis of variance indicated no statistically significant differences for regrowth.

Acc.	Regrowth (%)	Forage Weight Regrowth (g)	Acc.	Rhizomes (%)*
9	33	1.25	7	64 a
3	30	1.95	9	44 a
5	30	0.94	10	37 a
4	19	0.81	1	0 b
1	13	0.35	2	0 b
7	11	0.29	3	0 b
11	10	1.34	4	0 b
2	0	0.00	5	0 b
6	0	0.00	6	0 b
8	0	0.00	8	0 b
10	0	0.00	11	0 b

*Chi square test; $\alpha = .05$

No additional water was applied at the Evans Farm site as would be the case on irrigated seed production fields. Thus, the data on seed production obtained in the present study (Table 16) may be of limited value to irrigated seed producers. It is estimated that 180 lbs/acre (200 kg/ha) would be extremely good production, given the risks involved with the pollination and seed harvesting of sweetvetch.

The use of sweetvetch has been limited because of a lack of commercially available seed and its high cost. For long-term persistence on semiarid rangelands it is important that sweetvetch produces abundant quantities of seed for subsequent establishment. Thus, it is important that a variety of sweetvetch be released to growers so that a good seed-producing sweetvetch can be made available at a reasonable cost.

No viable seed was produced during the initial establishment year; however, some flowering was observed. Seed production was estimated from plants in their second growing season in the field nursery at Evans Farm (Table 16). Considerable variation existed in seed production among the 11 sweetvetch accessions, supporting Hypothesis 2. If these differences are converted to a per hectare basis, the differences would have been even more pronounced. Accession 5 was the best seed producer, but not significantly superior to Accession 6.

Correlations

A correlation matrix was constructed to estimate the degree of association among the variables in the study (Appendix B). Such a large correlation matrix is difficult to interpret with a total of 237 significant correlations. However, field forage weight from Harvest 1 and seed production were probably the two most important variables

Table 16. Seed production (g/plant) of the 11 sweetvetch accessions at Evans Farm during the second growing season. Values represent the means of 8 replicates.

Accession	Seed (g/plant)*
5	9.0 a
6	5.8 ab
1	4.3 bc
2	3.6 bc
9	3.3 bc
3	3.2 bc
7	3.0 bc
4	2.8 bc
11	1.6 bc
10	0.2 c
8	0.1 c
*L.S.D. (.05)	4.26

examined in this study. These two variables were significantly and positively correlated (r = 0.66). Total crude protein and nodule mass from the field for Harvest 1 were significantly correlated with both field forage production from Harvest 1 and field seed production. The high correlation (r = 0.99) between forage weight and total crude protein was expected because the forage weights were used to calculate values of total crude protein. Significant correlations were also found between nodule mass for the first field harvest and forage weight (r = 0.89) and between nodule mass for the first field harvest and seed production (r = 0.62). In addition, total acetylene reduction at the first field harvest was significantly correlated (r = 0.73) with forage weight at the first field harvest. These three correlations suggest that biological nitrogen fixation was important in determining both forage and seed production in the field.

SUMMARY AND CONCLUSIONS

Sweetvetch exhibited considerable variability among the accessions investigated. Some accessions performed better than others under wet or dry conditions under the greenhouse line-source sprinkler system. Accession 5 exhibited superior performance under the high water levels. Accession 3 did the best under the low water levels and may be the best choice for use on arid, nitrogen-limited sites. Accession 7 exhibited superior rhizome development and may be valuable for stabilizing erodible sites.

The primary contribution of sweetvetch for forage is apparently limited to the early spring period. Its potential use as a late-fall or winter forage in the Intermountain West appears minimal, as evidenced by its prostrate fall growth and limited forage production during this period. However, there may be potential for selecting sweetvetch accessions with an ability to regrow during the fall.

Sweetvetch is capable of fixing significant amounts of nitrogen as evidenced by its acetylene reduction activities. Consequently, sweetvetch may be an excellent species for use in nitrogen-limited environments. In addition, because it is native to the Intermountain West, sweetvetch may be an important species for use in reclamation whenever regulations mandate the use of native species.

Seed costs and availability have limited the use of sweetvetch to date. Therefore, seed production may be one of the most important characteristics to consider in sweetvetch. Because Accession 5 exhibited superior seed production, it may have considerable potential.

Sweetvetch appears to be an effective legume for inclusion in rangeland or mineland seedings in western North America. The potential for improving sweetvetch through breeding and selection appears promising.

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APPENDIXES

Appendix A: Analysis of Variance Tables

Source	DF	Mean Squares	F	Sign. level
Analysis of variance table for syn. 1 seed weights for all 11 accessions. (Note Table 2)				
REP (R)	3	0.000286	1.175	.336
ACC (A)	10	0.006213	25.549	.000
ERROR	30	0.000243	25.549	.000
Analysis of variance table for seed weights from original collections. (Note Table 2)				
REP (R)	3	0.000122	.796	.506
ACC (A)	10	0.004870	31.797	.000
ERROR	30	0.000153		
Analysis of variance table for total root length for all 11 accessions at the 10 different levels of water application. (Note Figure 6)				
REP (R)	2	4.275886	N.V.	N.V.
WAT (W)	9	7.146977	N.V.	N.V.
ACC (A)	10	1.001514	2.503	.007
WA	90	0.465081	1.162	.000
ERROR	218	0.400137		
Analysis of variance table for green leaf area of all 11 accessions at the different levels of water application. (Note Figure 7)				
REP (R)	2	5.953233	N.V.	N.V.
WAT (W)	9	84.212135	N.V.	N.V.
ACC (A)	10	10.793597	4.287	.000
WA	90	3.758470	1.493	.000
ERROR	218	2.517477		
Analysis of variance table for root lengths of the 11 accessions at three hypothetical levels of water application. (Note Table 3)				
REP (R)	2	4.275886	N.V.	N.V.
WAT (W)	2	16.765511	N.V.	N.V.
ACC (A)	10	0.903423	1.899	.045
WA	20	0.976450	2.052	.006
ERROR	295	0.475763		

Analysis of variance table for green leaf area of all 11 accessions at three hypothetical levels of water application. (Note Table 4)

REP (R)	2	5.953233	N.V.	N.V.
WAT (W)	2	289.230367	N.V.	N.V.
ACC (A)	10	11.061458	3.596	.000
WA	20	7.958289	2.587	.000
ERROR	295	3.075780		

Analysis of variance table for shoot mass for all 11 accessions at three hypothetical levels of water application. (Note Table 5)

REP (R)	2	0.001619	N.V.	N.V.
WAT (W)	2	0.023224	N.V.	N.V.
ACC (A)	10	0.002202	4.944	.000
WA	20	0.001019	2.288	.002
ERROR	295	0.000445		

Analysis of variance table for root mass of the 11 accessions of 3 hypothetical levels of water application. (Note Table 6)

REP (R)	2	0.005047	N.V.	N.V.
WAT (W)	2	0.025904	N.V.	N.V.
ACC (A)	10	0.001867	3.096	.001
WA	20	0.001443	2.393	.001
ERROR	295	0.000603		

Analysis of variance table for total acetylene reduction for all 11 accessions under three hypothetical levels of water application. (Note Table 7)

REP (R)	2	6.810566	N.V.	N.V.
WAT (W)	2	44.30633	N.V.	N.V.
ACC (A)	10	2.941546	5.214	.000
AW	20	1.991569	3.530	.000
ERROR	295	.564207		

Analysis of variance table for specific nodule activity of all 11 accessions at three hypothetical levels of water application. (Note Table 8)

REP (R)	2	351578.51	N.V.	N.V.
WAT (W)	2	1416923.90	N.V.	N.V.
ACC (A)	10	58541.09	.828	.602
WA	20	56172.57	.794	.721
ERROR	295	70734.90		

Analysis of variance table for nodule mass at three hypothetical levels of water application. (Note Table 9)

REP (R)	2	0.000034	N.V.	N.V.
WAT (W)	2	0.000490	N.V.	N.V.
ACC (A)	10	0.000076	5.531	.000
WA	20	0.000030	2.183	.003
ERROR	295	0.000014		

Analysis of variance table for nodule number for the 11 accessions at 3 hypothetical levels of water applications. (Note Figure 10)

REP (R)	2	4.457567	N.V.	N.V.
WAT (W)	2	581.136111	N.V.	N.V.
ACC (A)	10	238.884757	6.668	.000
WA	20	37.236667	1.039	.415
ERROR	295	35.823546		

Analysis of variance table for seed production from plants at Evans Farm. (Note Table 11)

REP (R)	7	17.738812	.987	.451
ACC (A)	10	44.138044	2.455	.017
ERROR	55	17.980544		

Analysis of variance for forage dry weights at the first harvest. (Note Table 12)

REP (R)	14	4906.350690	1.047	.300
ACC (A)	11	62573.452891	13.355	.000
ERROR	112	4685.468352		

Analysis of variance for crude protein percent at the first harvest. (Note Table 12)

REP (R)	3	2.411967	.57245	0.637
ACC (A)	11	5.917946	1.404	0.217
ERROR	33	4.213385		

Analysis of variance table for total crude protein at the first harvest. (Note Table 12)

REP (R)	14	109.565571	.844869	0.620
ACC (A)	11	1375.092608	10.603455	0.000
ERROR	112	129.683456		

Analysis of variance table for in vitro digestibility at the first harvest. (Note Table 12)

REP (R)	3	10.415556	.409	.747
ACC (A)	11	75.116818	2.953	.008
ERROR	33	25.438131		

Analysis of variance table for total acetylene reduced at the first harvest at Evans Farm. (Note Table 13)

REP (R)	11	20445.34	6.008	.000
ACC (A)	10	11025.99	3.240	.001
ERROR	80	3403.10		

Analysis of variance table for specific nodule activity at the first harvest at Evans farm. (Note Table 13)

REP (R)	11	7239.53	1.766	.074
ACC (A)	10	13023.02	3.178	.002
ERROR	80	4098.46		

Analysis of variance table for nodule mass at the first harvest. (Note Table 13)

REP (R)	11	0.400861	1.491	.151
ACC (A)	10	0.887626	3.301	.001
ERROR	80	0.268876		

Analysis of variance table for forage weights at the second harvest. (Note Table 14)

REP (R)	10	49722.395370	1.183	.312
ACC (A)	11	975227.943382	23.206	.000
ERROR	94	42025.536753		

Analysis of variance table for percent crude protein at the second harvest. (Note Table 14)

REP (R)	3	0.909930	.547926	.653
ACC (A)	11	8.963193	5.3977304	.000
ERROR	33	1.660680		

Analysis of variance table for total crude protein at the second harvest. (Note Table 14)

REP (R)	10	538.127581	1.138441	.343
ACC (A)	11	11429.984058	24.180815	.000
ERROR	94	472.688115		

Analysis of variance table for in-vitro dry matter digestibility at the second harvest. (Note Table 14)

REP (R)	3	102.180386	.888969	.457
ACC (A)	11	136.500617	1.187555	.333
ERROR	33	114.942577		

Analysis of variance table for total acetylene reduction at the second harvest. (Note Table 15)

REP (R)	10	0.510065	.660460	.757
ACC (A)	10	1.365300	1.767865	.083
ERROR	70	0.772288		

Analysis of variance table for specific nodule activity at the second harvest. (Note Table 15)

REP (R)	10	17.942709	1.265404	.267
ACC (A)	10	9.400468	.69	.723
ERROR	70	14.179428		

Analysis of variance table for nodule mass at the second harvest. (Note Table 15)

REP (R)	10	0.082339	.651503	.765
ACC (A)	10	0.683469	5.407925	.000
ERROR	70	0.126383		

Analysis of variance table for fall regrowth. (Note Table 16)

REP (R)	10	5.934491	1.604	.117
ACC (A)	11	4.427229	1.196	.300
ERROR	94	3.700550		

Appendix B: Correlation Matrix

Key

PRE = Mean annual precipitation at site of origin

SWOC = Seed weight of original collections

SWS1 = Seed weight of Syn. 1 generation

SM1 = Shoot mass at water levels 1-3

SM2 = Shoot mass at water levels 4-7

SM3 = Shoot mass at water levels 8-10

RM1 = Root mass at water levels 1-3

RM2 = Root mass at water levels 4-7

RM3 = Root mass at water levels 8-10

RL1 = Root length at water levels 1-3

RL2 = Root length at water levels 4-7

RL3 = Root length at water levels 8-10

LA1 = Green leaf area at water levels 1-3

LA2 = Green leaf area at water levels 4-7

LA3 = Green leaf area at water levels 8-10

NN1 = Number of nodules at water levels 1-3

NN2 = Number of nodules at water levels 4-7

NN3 = Number of nodules at water levels 8-10

NM1 = Nodule mass at water levels 1-3

NM2 = Nodule mass at water levels 4-7

NM3 = Nodule mass at water levels 8-10

TAR1 = Total acetylene reduction activity at water levels 1-3

TAR2 = Total acetylene reduction activity at water levels 4-7

TAR3 = Total acetylene reduction activity at water levels 8-10

SNA1 = Specific nodule activity at water levels 1-3

SNA2 = Specific nodule activity at water levels 4-7

SNA3 = Specific nodule activity at water levels 8-10

FW1 = Forage weights for first field harvest

CP1 = Crude protein percent for first field harvest

TCP1 = Total crude protein for first field harvest

IV1 = IVDMD for first field harvest

FW2 = Forage weights for second field harvest

CP2 = Crude protein percent for second field harvest

TCP2 = Total crude protein for second field harvest

IV2 = IVDMD for second field harvest

FAR1 = Total acetylene reduction for first field harvest

FSN1 = Specific nodule activity for first field harvest

FNM1 = Nodule mass for first field harvest

FAR2 = Total acetylene reduction for second field harvest

FSN2 = Specific nodule activity for second field harvest

FNM2 = Nodule mass for second field harvest

REGR = Fall regrowth percent

RGFW = Fall regrowth forage weight

RHIZ = Rhizome percent

SEPR = Seed production

Note:

$P < .05; r > 0.602$

$P < .01; r > 0.735$

MATRIX

	PRE	SWOC	SWS1	SM1	SM2	SM3	RM1
PRE	1.000	-0.061	-0.085	0.150	0.071	0.030	0.307
SWOD	-0.061	1.000	0.789	0.582	0.579	0.263	-0.107
SWS1	-0.085	0.789	1.000	0.591	0.557	0.613	0.102
SM1	0.150	0.582	0.591	1.000	0.640	0.169	0.703
SM2	0.071	0.579	0.557	0.640	1.000	-0.166	0.362
SM3	0.030	0.263	0.613	0.169	-0.166	1.000	-0.054
RM1	0.307	-0.107	0.102	0.703	0.362	-0.054	1.000
RM2	0.253	0.105	0.217	0.237	0.696	-0.328	0.416
RM3	-0.253	-0.201	0.203	-0.242	-0.280	0.691	-0.082
RL1	0.289	0.164	0.171	0.729	0.353	-0.148	0.793
RL2	-0.139	0.396	0.330	0.442	0.630	-0.417	0.386
RL3	-0.374	-0.026	0.323	-0.155	-0.274	0.743	-0.149
LA1	0.231	0.351	0.394	0.922	0.431	0.128	0.817
LA2	0.108	0.611	0.708	0.761	0.799	0.111	0.461
LA3	-0.124	-0.438	-0.103	-0.576	-0.661	0.548	-0.355
NN1	0.189	0.223	0.309	0.534	0.489	0.038	0.515
NN2	-0.354	0.332	0.284	0.332	0.362	0.038	0.091
NN3	-0.128	-0.042	0.161	0.048	-0.166	0.473	0.067
NM1	0.242	0.092	-0.112	0.483	0.377	-0.351	0.526
NM2	0.132	0.372	0.379	0.702	0.607	0.037	0.615
NM3	-0.230	-0.172	0.072	-0.159	-0.490	0.716	-0.152
TAR1	0.342	0.285	0.304	0.810	0.505	0.077	0.808
TAR2	-0.018	0.090	0.323	0.302	-0.037	0.222	0.398
TAR3	-0.147	-0.381	-0.412	-0.500	-0.752	0.219	-0.329
SNA1	0.051	0.457	0.546	0.596	0.467	0.175	0.385
SNA2	0.439	-0.445	-0.382	-0.210	-0.358	-0.222	0.232

	PRE	SWOC	SWS1	SM1	SM2	SM3	RM1
SNA3	-0.073	-0.390	-0.539	-0.485	-0.522	-0.227	-0.229
FW1	-0.000	0.410	0.536	0.769	0.222	0.563	0.513
CP1	-0.298	0.359	0.673	0.311	0.569	0.267	0.074
TCP1	-0.033	0.438	0.601	0.792	0.313	0.566	0.519
IV1	0.302	0.125	0.392	-0.134	-0.084	0.648	-0.168
FW2	0.198	-0.056	-0.237	0.196	-0.105	0.013	0.206
CP2	-0.339	0.091	-0.180	-0.151	-0.232	-0.253	-0.323
TCP2	0.014	0.022	-0.344	0.126	-0.281	-0.068	0.003
IV2	-0.258	-0.448	-0.638	-0.424	-0.159	-0.677	-0.061
FAR1	-0.183	0.209	0.480	0.484	0.329	0.523	0.347
FSN1	-0.260	-0.265	0.210	-0.003	-0.067	0.488	0.147
FNM1	-0.056	0.545	0.713	0.788	0.453	0.588	0.417
FAR2	0.177	-0.179	-0.524	-0.171	-0.080	-0.375	-0.043
FSN2	-0.434	0.148	-0.308	-0.139	-0.097	-0.522	-0.309
FNM2	0.349	-0.563	-0.725	-0.276	-0.393	-0.272	0.109
REGR	0.282	-0.141	0.300	0.179	0.319	0.252	0.455
RGFW	0.085	-0.372	-0.005	0.025	0.226	-0.022	0.321
RHIZ	0.562	-0.177	-0.052	0.116	0.155	-0.179	0.438
SEPR	0.087	0.297	0.537	0.392	-0.129	0.679	0.256

	RM2	RM3	RL1	RL2	RL3	LA1	LA2
PRE	0.253	-0.253	0.289	-0.139	-0.374	0.231	0.108
SWOC	0.105	-0.201	0.164	0.396	-0.026	0.351	0.611
SWS1	0.217	0.203	0.171	0.330	0.323	0.394	0.708
SM1	0.237	-0.242	0.729	0.442	-0.155	0.922	0.761
SM2	0.696	-0.280	0.353	0.630	-0.274	0.431	0.799
SM3	-0.328	0.691	-0.148	-0.417	0.743	0.128	0.111
RM1	0.416	-0.082	0.793	0.386	-0.149	0.817	0.461
RM2	1.000	-0.117	0.231	0.708	-0.168	0.242	0.571
RM3	-0.117	1.000	-0.392	-0.336	0.918	-0.221	-0.244
RL1	0.231	-0.392	1.000	0.527	-0.374	0.724	0.488
RL2	0.708	-0.336	0.527	1.000	-0.271	0.376	0.579
RL3	-0.168	0.918	-0.374	-0.271	1.000	-0.112	-0.054
LA1	0.242	-0.221	0.724	0.376	-0.112	1.000	0.678
LA2	0.571	-0.244	0.488	0.579	-0.054	0.678	1.000
LA3	-0.355	0.669	-0.508	-0.601	0.740	-0.425	-0.346
NN1	0.539	-0.060	0.504	0.459	0.133	0.578	0.759
NN2	0.134	-0.010	0.221	0.286	0.283	0.278	0.588
NN3	-0.026	0.510	-0.026	-0.110	0.728	0.161	0.224
NM1	0.376	-0.382	0.583	0.392	-0.225	0.568	0.512
NM2	0.514	-0.053	0.604	0.525	0.106	0.703	0.777
NM3	-0.498	0.783	-0.269	-0.547	0.849	-0.112	-0.256
TAR1	0.465	-0.070	0.651	0.418	0.001	0.894	0.662
TAR2	0.224	0.039	0.401	0.376	0.282	0.499	0.496
TAR3	-0.443	0.386	-0.414	-0.502	0.548	-0.257	-0.438
SNA1	0.413	-0.052	0.096	0.367	0.014	0.650	0.569
SNA2	0.054	-0.254	0.166	-0.082	-0.319	0.038	-0.191

	RM2	RM3	RL1	RL2	RL3	LA1	LA2
SNA3	-0.118	-0.019	-0.346	-0.229	0.147	-0.191	-0.278
FW1	-0.057	0.226	0.383	0.050	0.398	0.809	0.548
CP1	0.304	0.106	0.149	0.314	0.240	0.118	0.693
TCP1	-0.003	0.223	0.400	0.087	0.403	0.800	0.633
IV1	-0.105	0.456	-0.151	-0.353	0.373	-0.217	-0.020
FW2	-0.313	-0.107	-0.011	-0.436	-0.143	0.315	-0.135
CP2	-0.172	-0.197	-0.014	0.240	-0.014	-0.153	-0.131
TCP2	-0.504	-0.202	-0.062	-0.407	-0.114	0.262	-0.226
IV2	0.172	-0.118	-0.302	0.125	-0.246	-0.276	-0.462
FAR1	0.114	0.542	0.150	0.056	0.581	0.399	0.397
FSN1	0.048	0.677	-0.146	-0.142	0.679	0.025	0.083
FAR2	0.018	0.252	0.394	0.135	0.367	0.659	0.626
FSN2	-0.023	-0.079	-0.268	-0.207	-0.271	-0.104	-0.472
FNM2	-0.122	-0.419	-0.033	0.268	-0.165	-0.093	-0.025
FNM2	-0.188	-0.002	-0.180	-0.467	-0.236	-0.096	-0.636
REGR	0.634	0.396	0.236	0.288	0.323	0.199	0.400
RGFR	0.467	0.187	0.082	0.130	0.140	0.060	0.263
RHIZ	0.420	-0.273	0.247	0.116	-0.389	0.266	0.187
SEPR	-0.083	0.384	0.325	0.122	0.503	0.431	0.263

	LA1	LA2	LA3	NN1	NN2	NN3	NM1
PRE	-0.124	0.189	-0.354	-0.128	0.242	0.132	-0.230
SWOC	-0.438	0.223	0.332	-0.042	0.092	0.372	-0.172
SWS1	-0.103	0.309	0.284	0.161	-0.112	0.379	0.072
SM1	-0.576	0.534	0.332	0.048	0.483	0.702	-0.159
SM2	-0.661	0.489	0.362	-0.166	0.377	0.607	-0.490
SM3	0.548	0.038	0.038	0.473	-0.351	0.037	0.716
RM1	-0.355	0.515	0.091	0.067	0.526	0.615	-0.152
RM2	-0.355	0.539	0.134	-0.026	0.376	0.514	-0.498
RM3	0.669	-0.060	-0.010	0.510	-0.382	-0.053	0.783
RL1	-0.508	0.504	0.221	-0.026	0.583	0.604	-0.269
RL2	-0.601	0.459	0.286	-0.110	0.392	0.525	-0.547
RL3	0.740	0.133	0.283	0.728	-0.225	0.106	0.849
LA1	-0.425	0.578	0.278	0.161	0.568	0.703	-0.112
LA2	-0.346	0.759	0.588	0.224	0.512	0.777	-0.256
LA3	1.000	-0.074	0.056	0.598	-0.329	-0.267	0.732
NN1	-0.074	1.000	0.733	0.654	0.825	0.920	0.093
NN2	0.056	0.733	1.000	0.640	0.649	0.737	0.235
NN3	0.598	0.654	0.640	1.000	0.393	0.505	0.765
NM1	-0.329	0.825	0.649	0.393	1.000	0.840	-0.115
NM2	-0.267	0.920	0.737	0.505	0.840	1.000	0.025
NM3	0.732	0.093	0.235	0.765	-0.115	0.025	1.000
TAR1	-0.371	0.757	0.380	0.330	0.743	0.875	-0.032
TAR2	0.268	0.540	0.384	0.481	0.303	0.462	0.081
TAR3	0.754	0.012	0.196	0.634	0.062	-0.102	0.651
SNA1	-0.338	0.215	-0.052	-0.063	0.038	0.292	-0.257
SNA2	0.136	-0.220	-0.433	-0.332	-0.071	-0.241	-0.381

	LA1	LA2	LA3	NN1	NN2	NN3	NM1
SNA3	0.467	0.007	0.164	0.287	0.193	-0.071	0.096
FW1	-0.019	0.556	0.442	0.555	0.394	0.644	0.436
CP1	0.067	0.449	0.586	0.262	0.054	0.390	0.031
TCP1	-0.020	0.605	0.519	0.561	0.404	0.688	0.412
IV1	0.440	-0.199	-0.182	-0.007	-0.451	-0.145	0.233
FW2	-0.117	-0.247	-0.139	-0.241	0.093	-0.015	-0.054
CP2	-0.033	0.173	0.275	0.325	0.232	0.018	0.163
TCP2	-0.096	-0.185	0.036	-0.045	0.226	-0.005	0.082
IV2	-0.180	-0.406	-0.316	-0.420	-0.082	-0.318	-0.393
FAR1	0.085	0.546	0.457	0.640	0.253	0.560	0.603
FSN1	0.503	0.323	0.204	0.667	-0.072	0.143	0.684
FNM1	-0.128	0.555	0.483	0.473	0.298	0.637	0.406
FAR2	-0.325	-0.402	-0.420	-0.417	0.009	-0.211	-0.210
FSN2	-0.135	0.127	0.515	0.121	0.421	0.154	-0.151
FNM2	-0.052	-0.433	-0.577	-0.322	-0.041	-0.342	-0.044
REGR	0.171	0.614	0.128	0.462	0.214	0.452	0.204
RGFW	0.158	0.526	0.177	0.422	0.247	0.271	0.170
RHIZ	-0.152	-0.045	-0.386	-0.450	0.002	0.004	-0.585
SEPR	0.245	0.376	0.114	0.564	0.038	0.315	0.523

	TAR1	TAR2	TAR3	SNA1	SNA2	SNA3	FW1
PRE	0.342	-0.018	-0.147	0.051	0.439	-0.073	-0.000
SWOC	0.285	0.090	-0.381	0.457	-0.445	-0.390	0.410
SWS1	0.304	0.323	-0.412	0.546	-0.382	-0.539	0.536
SM1	0.810	0.302	-0.500	0.596	-0.210	-0.485	0.769
SM2	0.505	-0.037	-0.752	0.467	-0.358	-0.522	0.222
SM3	0.077	0.222	0.219	0.175	-0.222	-0.227	0.563
RM1	0.808	0.398	-0.329	0.385	0.232	-0.229	0.513
RM2	0.465	0.224	-0.443	0.413	0.054	-0.118	-0.057
RM3	-0.070	0.039	0.386	-0.052	-0.254	-0.019	0.226
RL1	0.651	0.401	-0.414	0.096	0.166	-0.346	0.383
RL2	0.418	0.376	-0.502	0.367	-0.082	-0.229	0.050
RL3	0.001	0.282	0.548	0.014	-0.319	0.147	0.398
LA1	0.894	0.499	-0.257	0.650	0.038	-0.191	0.809
LA2	0.662	0.496	-0.438	0.569	-0.191	-0.278	0.548
LA3	-0.371	0.268	0.754	-0.338	0.136	0.467	-0.019
NN1	0.757	0.540	0.012	0.215	-0.220	0.007	0.556
NN2	0.380	0.384	0.196	-0.052	-0.433	0.164	0.442
NN3	0.330	0.481	0.634	-0.063	-0.332	0.287	0.555
NM1	0.743	0.303	0.062	0.038	-0.071	0.193	0.394
NM2	0.875	0.462	-0.102	0.292	-0.241	-0.071	0.644
NM3	-0.032	0.081	0.651	-0.257	-0.381	0.096	0.436
TAR1	1.000	0.418	-0.154	0.537	-0.056	-0.110	0.750
TAR2	0.418	1.000	0.255	0.331	0.366	0.335	0.434
TAR3	-0.154	0.255	1.000	-0.321	0.123	0.796	0.083
SNA1	0.537	0.331	-0.321	1.000	-0.022	-0.148	0.536
SNA2	-0.056	0.366	0.123	-0.022	1.000	0.470	-0.326

	TAR1	TAR2	TAR3	SNA1	SNA2	SNA3	FW1
SNA3	-0.110	0.335	0.796	-0.148	0.470	1.000	-0.162
FW1	0.750	0.434	0.083	0.536	-0.325	-0.162	1.000
CP1	0.072	0.298	-0.363	0.107	-0.354	-0.376	0.208
TCP1	0.742	0.447	0.016	0.521	-0.357	-0.211	0.987
IV1	-0.186	0.054	0.000	-0.144	0.239	-0.134	-0.055
FW2	0.239	-0.157	0.146	0.193	0.333	0.304	0.241
CP1	-0.131	0.054	0.308	-0.227	-0.419	0.128	-0.022
TCP2	0.185	-0.125	0.402	0.087	0.132	0.462	0.294
IV2	-0.208	-0.234	0.103	0.017	0.313	0.464	-0.507
FAR1	0.512	0.074	-0.027	0.243	-0.714	-0.427	0.730
FSN1	0.093	0.156	0.197	0.063	-0.450	-0.197	0.380
FNM1	0.628	0.211	-0.206	0.403	-0.601	-0.530	0.886
FAR2	0.038	-0.594	0.057	0.053	0.094	0.211	-0.211
FSN2	-0.069	0.141	0.382	-0.207	-0.080	0.574	-0.121
FNM2	-0.013	-0.466	0.216	-0.109	0.373	0.292	-0.214
REGR	0.408	0.295	-0.166	0.153	-0.141	-0.318	0.225
RGFW	0.198	0.090	-0.106	0.017	-0.248	-0.217	0.087
RHIZ	0.215	0.274	-0.287	0.323	0.834	0.152	-0.171
SEPR	0.386	0.559	0.166	0.270	-0.179	-0.237	0.657

	CP1	TCP1	IV1	FW2	CP2	TCP2	IV2
PRE	-0.298	-0.033	0.302	0.198	-0.339	0.014	-0.258
SWOC	0.359	0.438	0.125	-0.056	0.091	0.022	-0.448
SWS1	0.673	0.601	0.392	-0.237	-0.180	-0.344	-0.638
SM1	0.311	0.792	-0.134	0.196	-0.151	0.126	-0.424
SM2	0.569	0.313	-0.084	-0.105	-0.232	-0.281	-0.159
SM3	0.267	0.566	0.648	0.013	-0.253	-0.068	-0.677
RM1	0.074	0.519	-0.168	0.206	-0.323	0.003	-0.061
RM2	0.304	-0.003	-0.105	-0.313	-0.172	-0.504	0.172
RM3	0.106	0.223	0.456	-0.107	-0.197	-0.202	-0.118
RL1	0.149	0.400	-0.151	-0.011	-0.014	-0.062	-0.302
RL2	0.314	0.087	-0.353	-0.436	0.240	-0.407	0.125
RL3	0.240	0.403	0.373	-0.143	-0.014	-0.114	-0.246
LA1	0.118	0.800	-0.217	0.315	-0.153	0.262	-0.276
LA2	0.693	0.633	-0.020	-0.135	-0.131	-0.226	-0.462
LA3	0.067	-0.020	0.440	-0.117	-0.033	-0.096	-0.180
NN1	0.449	0.605	-0.199	-0.247	0.173	-0.185	-0.406
NN2	0.586	0.519	-0.182	-0.139	0.275	0.036	-0.316
NN3	0.262	0.561	-0.007	-0.241	0.325	-0.045	-0.420
NM1	0.054	0.404	-0.451	0.093	0.232	0.226	-0.082
NM2	0.390	0.688	-0.145	-0.015	0.018	-0.005	-0.318
NM3	0.031	0.412	0.233	-0.054	0.163	0.082	-0.393
TAR1	0.072	0.742	-0.186	0.239	-0.131	0.185	-0.208
TAR2	0.298	0.447	0.054	-0.157	0.054	-0.125	-0.234
TAR3	-0.363	0.016	0.000	0.146	0.308	0.402	0.103
SNA1	0.107	0.521	-0.144	0.193	-0.227	0.087	0.017
SNA2	-0.354	-0.357	0.239	0.333	-0.419	0.132	0.313

	CP1	TCP1	IV1	FW2	CP2	TCP2	IV2
SNA3	-0.376	-0.211	-0.134	0.304	0.128	0.462	0.464
FW1	0.208	0.987	-0.055	0.241	-0.022	0.294	-0.507
CP1	1.000	0.350	0.225	-0.447	-0.137	-0.576	-0.521
TCP1	0.350	1.000	-0.015	0.191	-0.068	0.210	-0.557
IV1	0.225	-0.015	1.000	0.079	-0.627	-0.221	-0.424
FW2	-0.447	0.191	0.079	1.000	-0.535	0.864	0.265
CP2	-0.137	-0.068	-0.627	-0.535	1.000	-0.046	-0.014
TCP2	-0.576	0.210	-0.221	0.864	-0.046	1.000	0.260
IV2	-0.521	-0.557	-0.424	0.265	-0.014	0.260	1.000
FAR1	0.418	0.760	-0.059	-0.182	0.068	-0.163	-0.471
FSN1	0.383	0.408	-0.041	-0.423	0.120	-0.417	-0.312
FNM1	0.479	0.920	0.038	-0.025	-0.011	-0.016	-0.688
FAR2	-0.766	-0.300	-0.212	0.619	-0.168	0.593	0.675
FSN2	-0.140	-0.139	-0.529	0.014	0.617	0.392	0.345
FNM2	-0.844	-0.314	-0.128	0.649	-0.265	0.566	0.580
REGR	0.415	0.273	0.127	-0.542	-0.088	-0.705	-0.340
RGFW	0.394	0.141	-0.258	-0.531	0.115	-0.587	-0.182
RHIZ	-0.100	-0.162	0.310	0.380	-0.714	0.004	0.230
SEPR	0.127	0.621	0.171	-0.329	0.260	-0.207	-0.634

	FAR1	FSN1	FNM1	FAR2	FSN2	FNM2	REGR
PRE	-0.183	-0.260	-0.056	0.177	-0.434	0.349	0.282
SWOC	0.209	-0.265	0.545	-0.179	0.148	-0.563	-0.141
SWS1	0.480	0.210	0.713	-0.524	-0.308	-0.725	0.300
SM1	0.484	-0.003	0.788	-0.171	-0.139	-0.276	0.179
SM2	0.329	-0.067	0.453	-0.080	-0.097	-0.393	0.319
SM3	0.523	0.488	0.588	-0.375	-0.522	-0.272	0.252
RM1	0.347	0.147	0.417	-0.043	-0.309	0.109	0.455
RM2	0.114	0.048	0.018	-0.023	-0.122	-0.188	0.634
RM3	0.542	0.677	0.252	-0.079	-0.419	-0.002	0.396
RL1	0.150	-0.146	0.394	-0.268	-0.033	-0.180	0.236
RL2	0.056	-0.142	0.135	-0.207	0.268	-0.467	0.288
RL3	0.581	0.679	0.367	-0.271	-0.165	-0.236	0.323
LA1	0.399	0.025	0.659	-0.104	-0.093	-0.096	0.199
LA2	0.397	0.083	0.626	-0.472	-0.025	-0.636	0.400
LA3	0.085	0.503	-0.128	-0.325	-0.135	-0.052	0.171
NN1	0.546	0.323	0.555	-0.402	0.127	-0.433	0.614
NN2	0.457	0.204	0.483	-0.420	0.515	-0.577	0.128
NN3	0.640	0.667	0.473	-0.417	0.121	-0.322	0.462
NM1	0.253	-0.072	0.298	0.009	0.421	-0.041	0.214
NM2	0.560	0.143	0.637	-0.211	0.154	-0.342	0.452
NM3	0.603	0.684	0.406	-0.210	-0.151	-0.044	0.204
TAR1	0.512	0.093	0.628	0.038	-0.069	-0.013	0.408
TAR2	0.074	0.156	0.211	-0.594	0.141	-0.466	0.295
TAR3	-0.027	0.197	-0.206	0.057	0.382	0.216	-0.166
SNA1	0.243	0.063	0.403	0.053	-0.207	-0.109	0.153
SNA2	-0.714	-0.450	-0.601	0.094	-0.080	0.373	-0.141

	FAR1	FSN1	FNM1	FAR2	FSN2	FNM2	REGR
SNA3	-0.427	-0.197	-0.530	0.211	0.574	0.292	-0.318
FW1	0.730	0.380	0.886	-0.211	-0.121	-0.214	0.225
CP1	0.418	0.383	0.479	-0.766	-0.140	-0.844	0.415
TCP1	0.760	0.408	0.920	-0.300	-0.139	-0.314	0.273
IV1	-0.059	-0.041	0.038	-0.212	-0.529	-0.128	0.127
FW2	-0.182	-0.423	-0.025	0.619	0.014	0.649	-0.542
CP2	0.068	0.120	-0.011	-0.168	0.617	-0.265	-0.088
TCP2	-0.163	-0.417	-0.016	0.593	0.392	0.566	-0.705
IV2	-0.471	-0.312	-0.688	0.675	0.345	0.580	-0.340
FAR1	1.000	0.773	0.865	-0.251	-0.300	-0.291	0.577
FSN1	0.773	1.000	0.470	-0.423	-0.405	-0.250	0.680
FNM1	0.865	0.470	1.000	-0.358	-0.259	-0.435	0.363
FAR2	-0.251	-0.423	-0.358	1.000	0.099	0.858	-0.406
FSN2	-0.300	-0.405	-0.259	0.099	1.000	-0.121	-0.536
FNM2	-0.291	-0.250	-0.435	0.858	-0.121	1.000	-0.283
REGR	0.577	0.680	0.363	-0.406	-0.536	-0.283	1.000
RGFW	0.518	0.759	0.227	-0.365	-0.352	-0.189	0.824
RHIZ	-0.491	-0.418	-0.337	0.142	-0.331	0.282	0.075
SEPR	0.524	0.460	0.618	-0.506	-0.254	-0.402	0.437

	RGFW	RHIZ	SEPR
PRE	0.085	0.562	0.087
SWOC	-0.372	-0.177	0.297
SWS1	-0.005	-0.052	0.537
SM1	0.025	0.116	0.392
SM2	0.226	0.155	-0.129
SM3	-0.022	-0.179	0.679
RM1	0.321	0.438	0.256
RM2	0.467	0.420	-0.083
RM3	0.187	-0.273	0.384
RL1	0.082	0.247	0.325
RL2	0.130	0.116	0.122
RL3	0.140	-0.389	0.503
LA1	0.060	0.266	0.431
LA2	0.263	0.187	0.263
LA3	0.158	-0.152	0.245
NN1	0.526	-0.045	0.376
NN2	0.177	-0.386	0.114
NN3	0.422	-0.450	0.564
NM1	0.247	0.002	0.038
NM2	0.271	0.004	0.315
NM3	0.170	-0.585	0.523
TAR1	0.198	0.215	0.386
TAR2	0.090	0.274	0.559
TAR3	-0.106	-0.287	0.166
SNA1	0.017	0.323	0.270
SNA2	-0.248	0.834	-0.179

	RGFW	RHIZ	SEPR
SNA3	-0.217	0.152	-0.237
FW1	0.087	-0.171	0.657
CP1	0.394	-0.100	0.127
TCP1	0.141	-0.162	0.621
IV1	-0.258	0.310	0.171
FW2	-0.531	0.380	-0.329
CP2	0.115	-0.714	0.260
TCP2	-0.587	0.004	-0.207
IV2	-0.182	0.230	-0.634
FAR1	0.518	-0.491	0.524
FSN1	0.759	-0.418	0.460
FNM1	0.227	-0.337	0.618
FAR2	-0.365	0.142	-0.506
FSN2	-0.352	-0.331	-0.254
FNM2	-0.189	0.282	-0.402
REGR	0.824	0.075	0.437
RGFW	1.000	-0.112	0.139
RHIZ	-0.112	1.000	-0.241
SEPR	0.139	-0.241	1.000

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